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ERC TR-8175

Straight and Chopped DC Performance Data for a Reliance EV-250AT Motor with a General Electric EV-1 Controller

Paul C. Edie
Eaton Corporation
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Prepared for
National Aeronautics and Space Administration
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NOTICE

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SUMMARY

This report is intended to supply the electric vehicle manufacturer with performance data on the Reliance EV-250AT shunt wound DC motor and General Electric EV-1 Chopper Controller. Data is provided for both straight and chopped DC input to the motor, at 2 motor temperature levels. Straight and chopped DC testing was done in the armature control mode at full field current for six values of armature voltage and one value of controller voltage. Straight DC testing was also done in the field control mode at full armature voltage for four values of field current. Data results are presented in both tabular and graphical forms. Tabular information includes motor voltage and current input data, motor speed and torque output data, power data and temperature data. Graphical information includes torque-speed, motor power output-speed, torque-current, and efficiency-speed plots under the various operating conditions.

The data resulting from this testing shows the speed-torque plots to have the most variance with operating temperature. The maximum motor efficiency is approximately 85% at low operating temperatures in the straight DC mode. When the chopper is utilized, maximum motor efficiency occurs when the chopper duty cycle approaches 100%. At low duty cycles the motor efficiency may be considerably less than the efficiency for straight DC. Chopper efficiency may be assumed to be 95% under all operating conditions. For equal speeds at a given voltage level, the motor operated in the chopped mode develops slightly more torque than it does in the straight DC mode.

INTRODUCTION

Today about one-half of the petroleum consumed in the United States is used for transportation. The introduction of electric vehicles could significantly shift the transportation energy base to other sources such as coal, nuclear, and solar.

In 1976 the Electric and Hybrid Vehicle Program was initiated within the Energy Research and Development Administration (ERDA), now the Department of Energy (DOE). In September of that same year, the Congress passed the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976 (Public Law 94-413). This Act is intended to accelerate the integration of electric and hybrid vehicles into our transportation system and to stimulate growth in the electric vehicle industry.

Part of the Electric and Hybrid Vehicle Program is focused upon assisting electric vehicle manufacturers with general technical problems relating to the design of near-term vehicles. For the most part, these manufacturers are small companies which often lack resources for testing, research, or development.

This report is intended to provide these manufacturers with performance data on an electric motor and chopper controller which may be used on this type of vehicle.

Due to the limited power and energy capability of batteries, high efficiency is a very desirable attribute of motors and controllers used in electric vehicles.

Although there is a great deal of electric motor and controller developmental work ongoing in both private industry and government research centers, the data supplied by the manufacturers of motors usually consists of limited information for straight DC operation only, and does not cover the motor's performance when used in conjunction with a chopper/controller.

The testing done under this contract and the resulting data formats were specified by the NASA Lewis Research Center. This report summarizes data on a Reliance EV-250AT shunt wound motor and a General Electric model EV-1 controller. This controller is designed for use with series motors. However, for the convenience of this test program, it was adapted to the shunt motor by adding a small choke in series with the motor. Other motor/controller combinations have also been tested, and appear as separate reports under the same contract number. To assure consistent tests results under severe load, the batteries used for these tests had much higher capacity than those typically available in an electric vehicle. If smaller, more portable power sources are used, the resulting motor torque and speed would be limited by the output capacity of the source.

All tests were made at two motor operating temperatures, as outlined in the "Test Procedure" section. The data from these tests should characterize the motor performance under typical "hot" and "cold" conditions. It should be noted that these are only representative temperature levels.

The data contained in these results is all of a steady-state nature, and does not show motor or controller efficiency during acceleration, deceleration or regenerative operation. To provide a complete range of data, motor nameplate ratings were exceeded in some instances for short periods of time. At no time were the motors exposed to severe abuse, physical shock or contaminated environments.

The test data presented here is not intended to represent the absolute maximum power available from any motor or controller. Under certain conditions, the motor or controller may be capable of exceeding the input and output power levels shown in the data and still remain undamaged. However, since this represents the extreme conditions of motor/controller operation and is useful only in limited circumstances, such data is not presented here.

Data is presented in graphical and tabular forms. Tests were run as detailed in the section titled "Test Procedure." Tabular data represents the arithmetic average of all test runs, and is intended to reduce data scatter as well as the volume of total data recorded. Tabular data will supply the user with performance information at a specific desired test point.

Graphical data presents the averaged results plotted and extrapolated, such that information for any given point within the testing range may be found.

EQUIPMENT TESTED

Description of Motor

The motor tested in this report is a Reliance Model EV-250AT shunt wound DC motor. This motor is shown in Figure 1, with a print detailing critical dimensions in Figure 2. Weight of this motor is 165.3 kg (365.4 lbs.) with all mounting hardware attached. The following nameplate data appears on the motor:

Frame	EV-250AT
HP	18
Type	TR
Identification No.	1LA803805T1 OE
Volts	96
Amps	160
RPM	1,800/4,000
Duty	Cont.
Amb.	40°C
Insulation	F
Power Supply	A
Field Volts	90
Field Amps	6.61/1.69
Winding	Stab. Shunt
Force Ventilated	

During inspection, prior to testing, no signs of abuse or wear were noted.

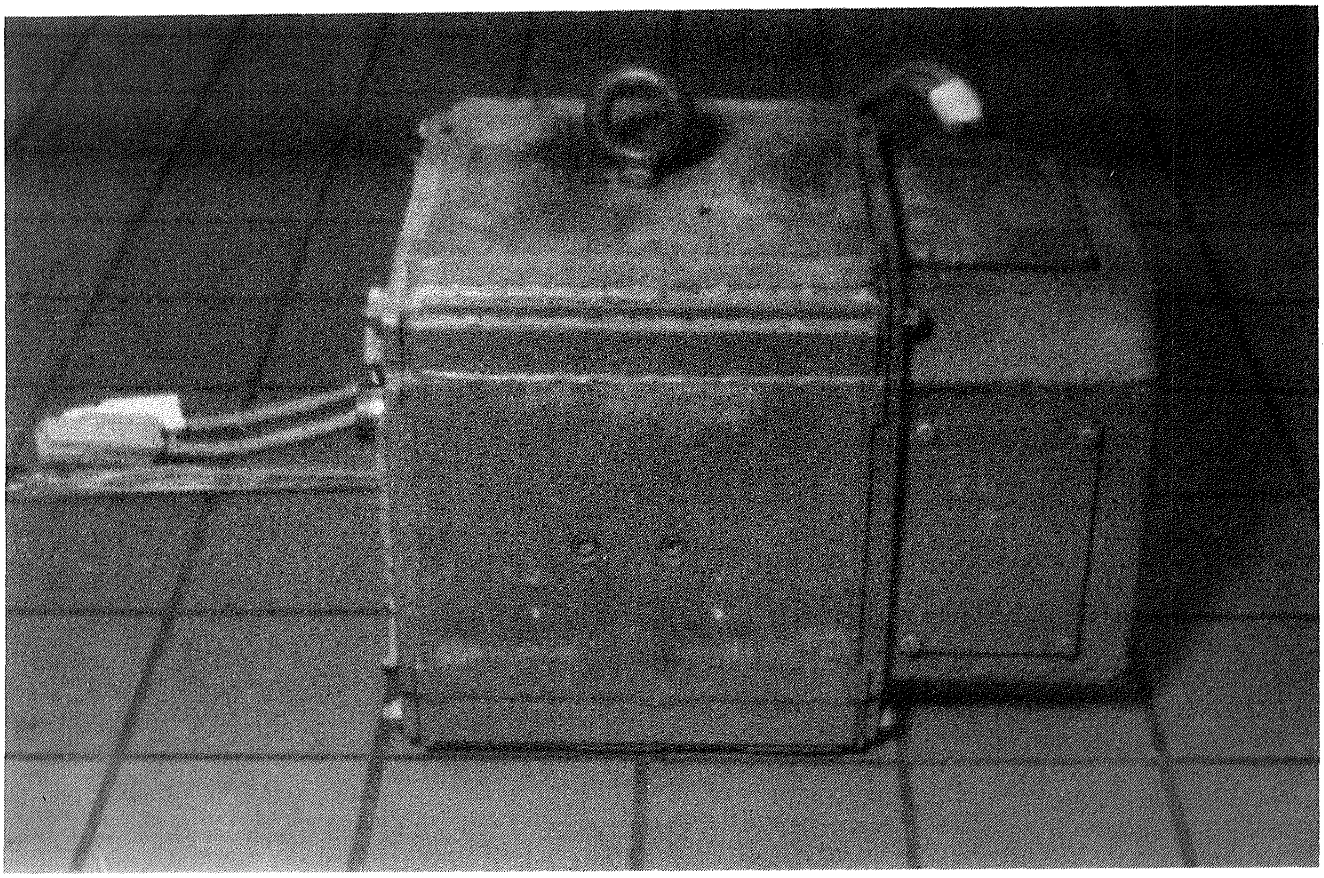


Figure 1 Reliance EV-250AT Motor

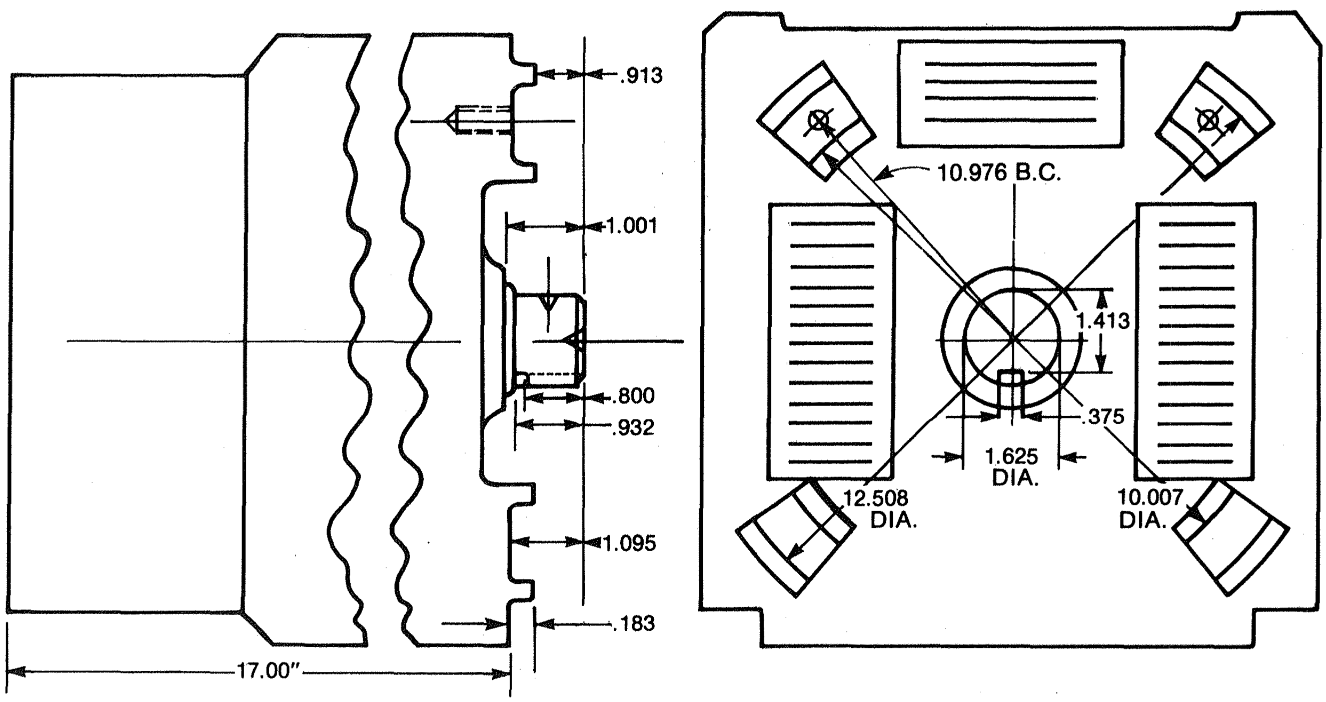


Figure 2 Outline Drawing of Reliance EV-250AT Motor

Description of Controller

The chopper/controller testing in conjunction with the Reliance motor was a General Electric model EV-1. This unit is a conventional SCR controller. The controller is shown in Figure 3, with a print detailing critical mounting dimensions in Figure 4. Weight of the controller is 24.3 Kg (53.7 lbs.). The only nameplate data on the controller is a 144 volt DC rating.

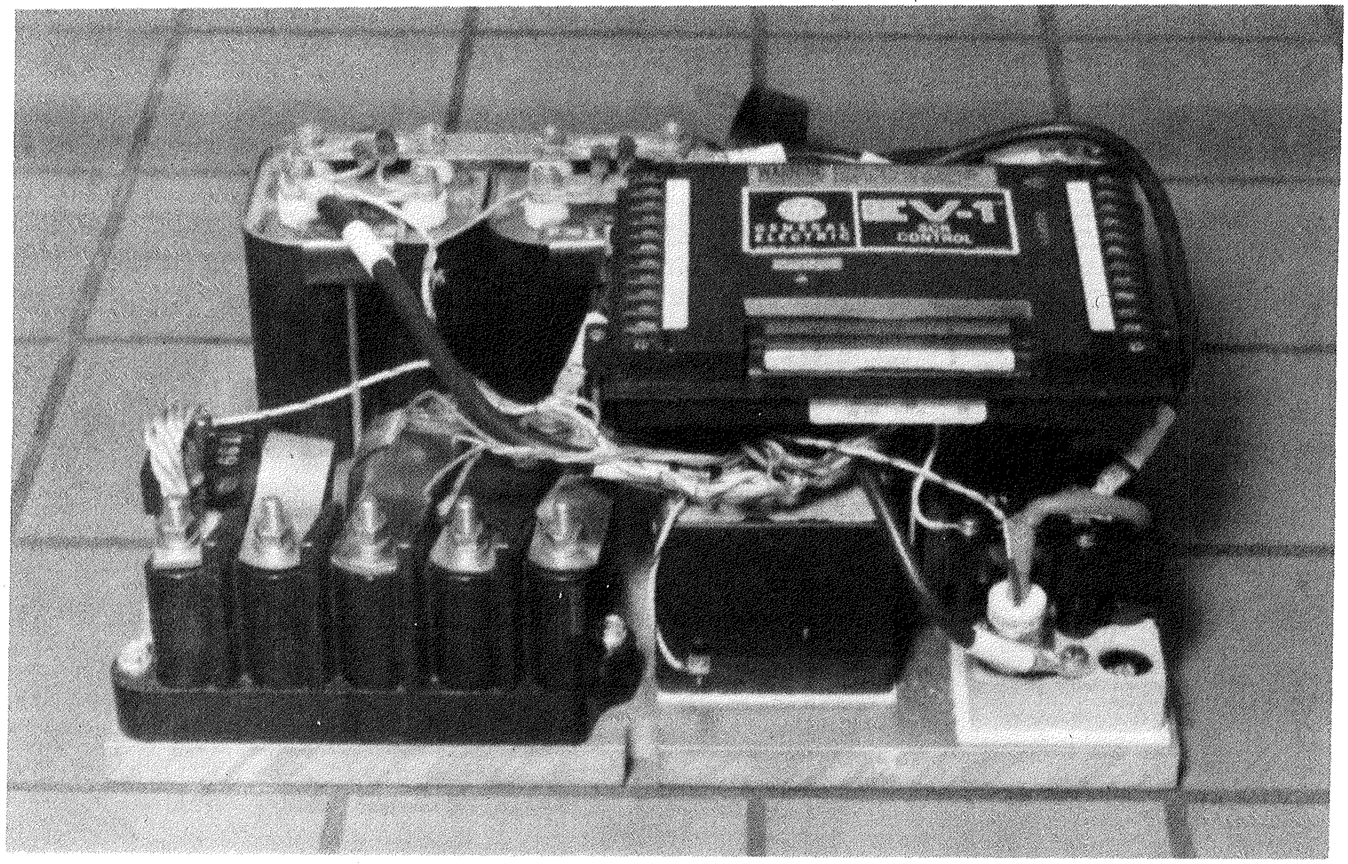


Figure 3 General Electric Model EV-1 Controller

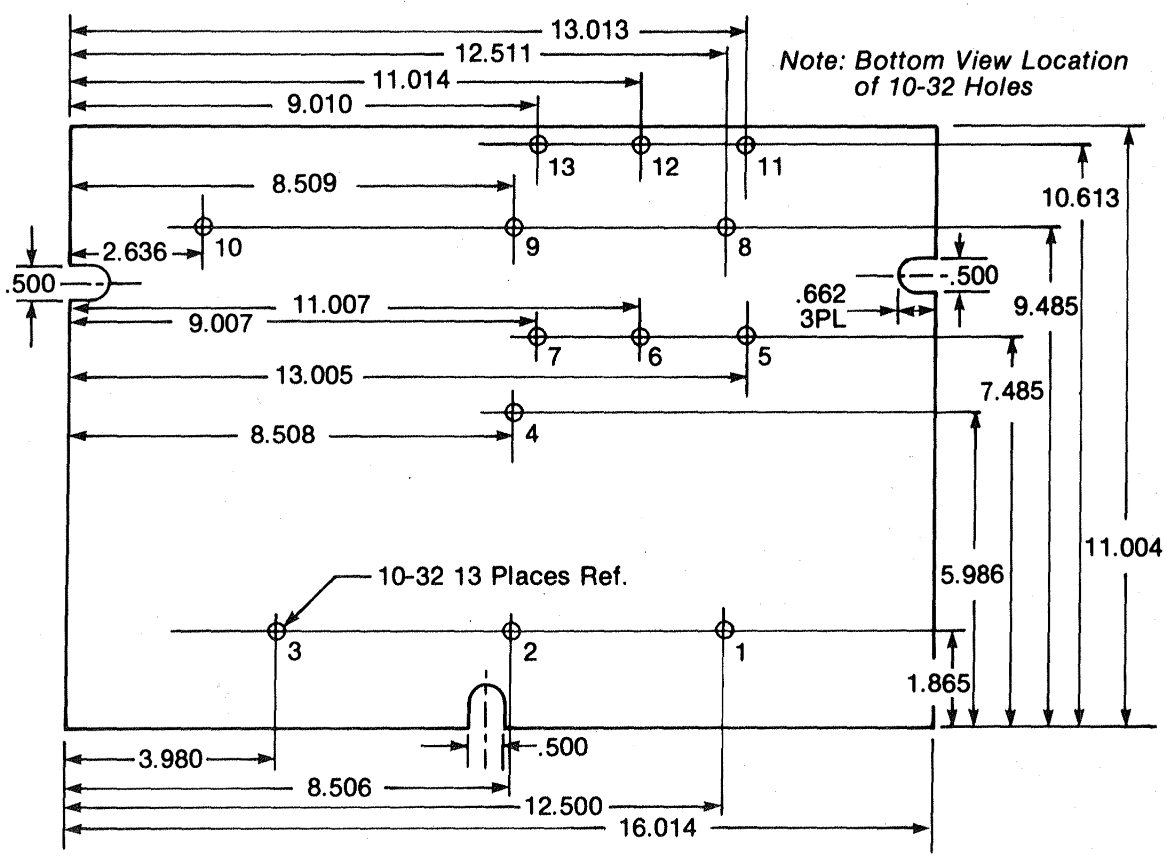


Figure 4 Drawing of General Electric EV-1 Controller Base Plate

TEST FACILITY

1. Dynamometer

The motor controller combination was mounted as shown in Figures 5-6. A conventional T-slot bedplate served as the mounting base. To absorb the motor output power, a General Electric DC dynamometer rated at 100 hp @ 6000 rpm was used. The dynamometer used a motor generator set as its source of DC power, and was controlled by a console located outside the test cell (Figure 7). The control console consisted of necessary dynamometer power and speed controls, along with a safety annunciator system to shut down the entire test cell should an overspeed, overcurrent or overtemperature condition occur. An automatic halogen fire extinguishing system was used to protect the entire testing area.

2. Power Source

To power the motor and controller, lead acid type batteries were used (Figure 8). Four 36 volt, 1100 amp hour batteries were wired in series using 4/0 copper stranded wire. Taps were wired at 6 volt increments from 0 to 144 volts. The batteries were charged using a Barrett current regulated industrial charger, rated at a capacity of 300 amps. Room air and hydrogen from the batteries were exhausted directly to the outside via overhead blowers.

Power for the motor field windings was supplied by a Sorenson DCR-150-18B DC power supply, rated at 150 volts at 18 amps. The supply had provisions for constant current and constant voltage operation.

3. Motor & Controller Installation

Figure 9 shows the motor mounting and transducer configuration. The motor was mounted directly on a small I-beam, which was in turn mounted on the bedplate. The motor was coupled to the telemetry transmitter (which is discussed in the Instrumentation section) by special machined slip fit couplings, held by a keyway. The transmitter assembly was coupled to the torque speed transducer (also discussed in the Instrumentation section) with Waldron Flex-Align couplings, which compensate for small alignment or balance errors. The opposite end of the torque/speed transducer was coupled to the dynamometer using another Waldron coupling.

All alignments between shafts were held to within 0.20 mm (0.008 in.) during setup.

The controller was mounted on a bench located directly over the motor to keep wire lengths as short as possible. All power wiring was accomplished using rubber insulated 4/0 stranded copper welding cable. Connections were made to the motor and controller via copper crimp type lugs.

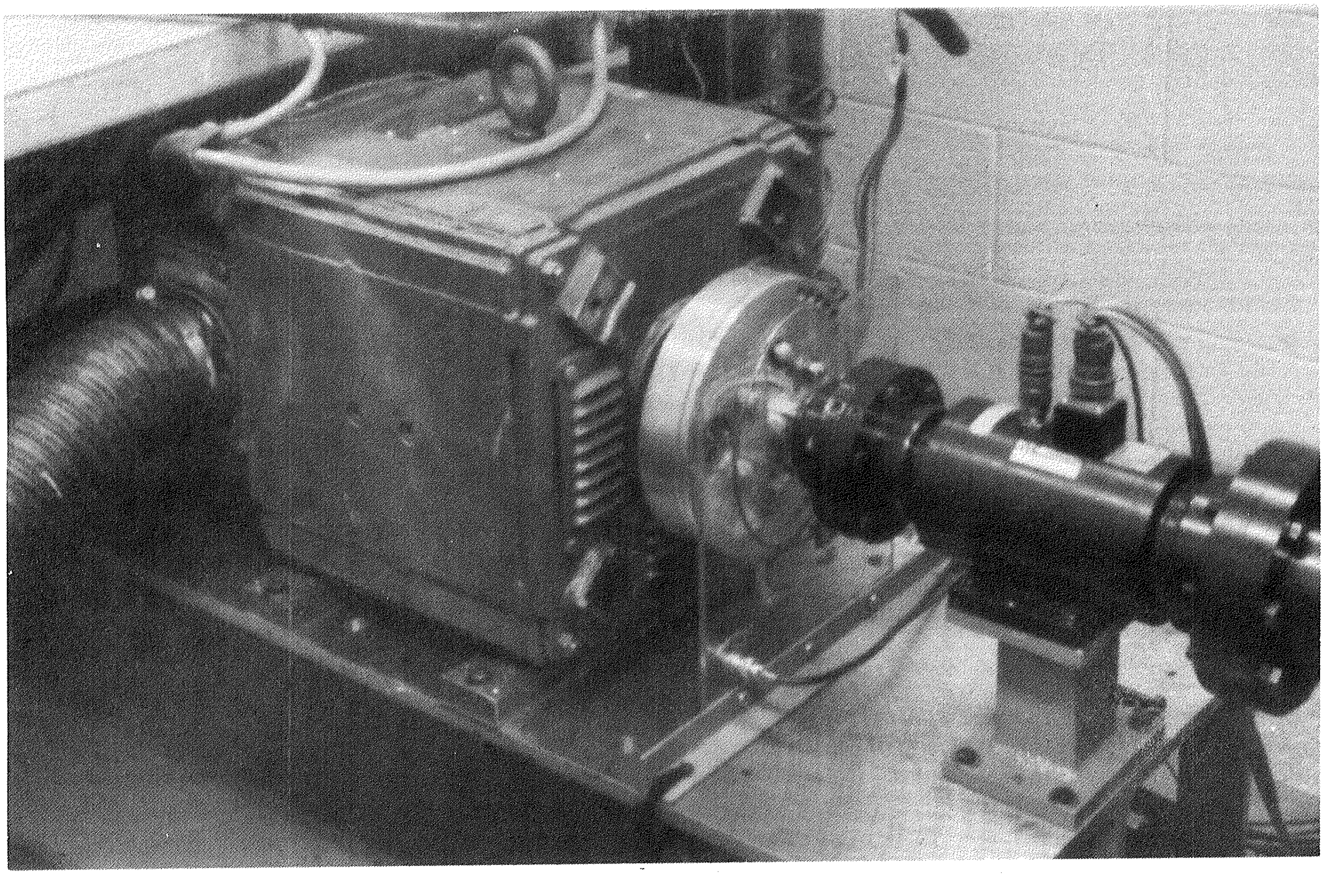


Figure 5 Mounting of Motor and Torque Transducer

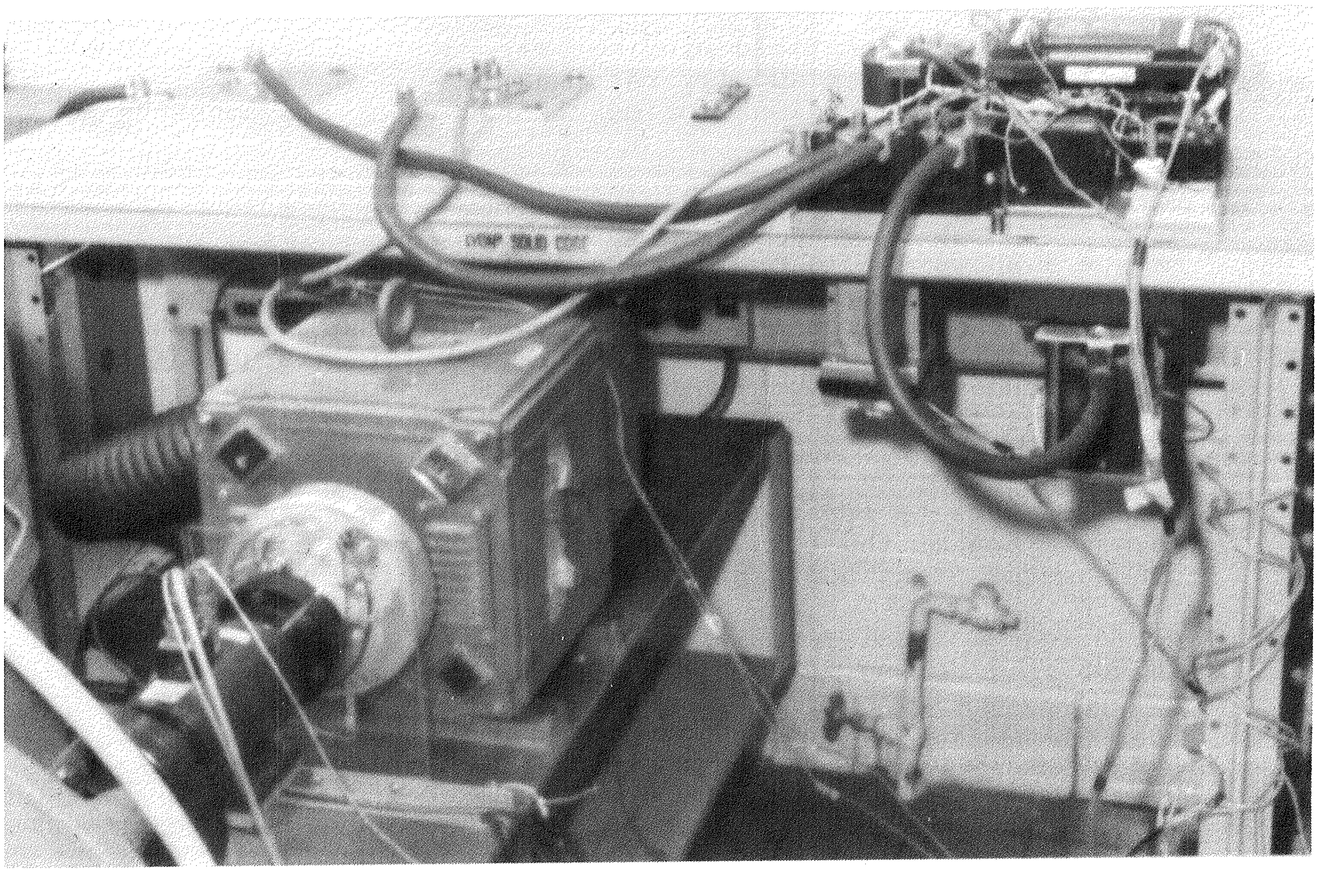


Figure 6 Mounting of Motor and Controller

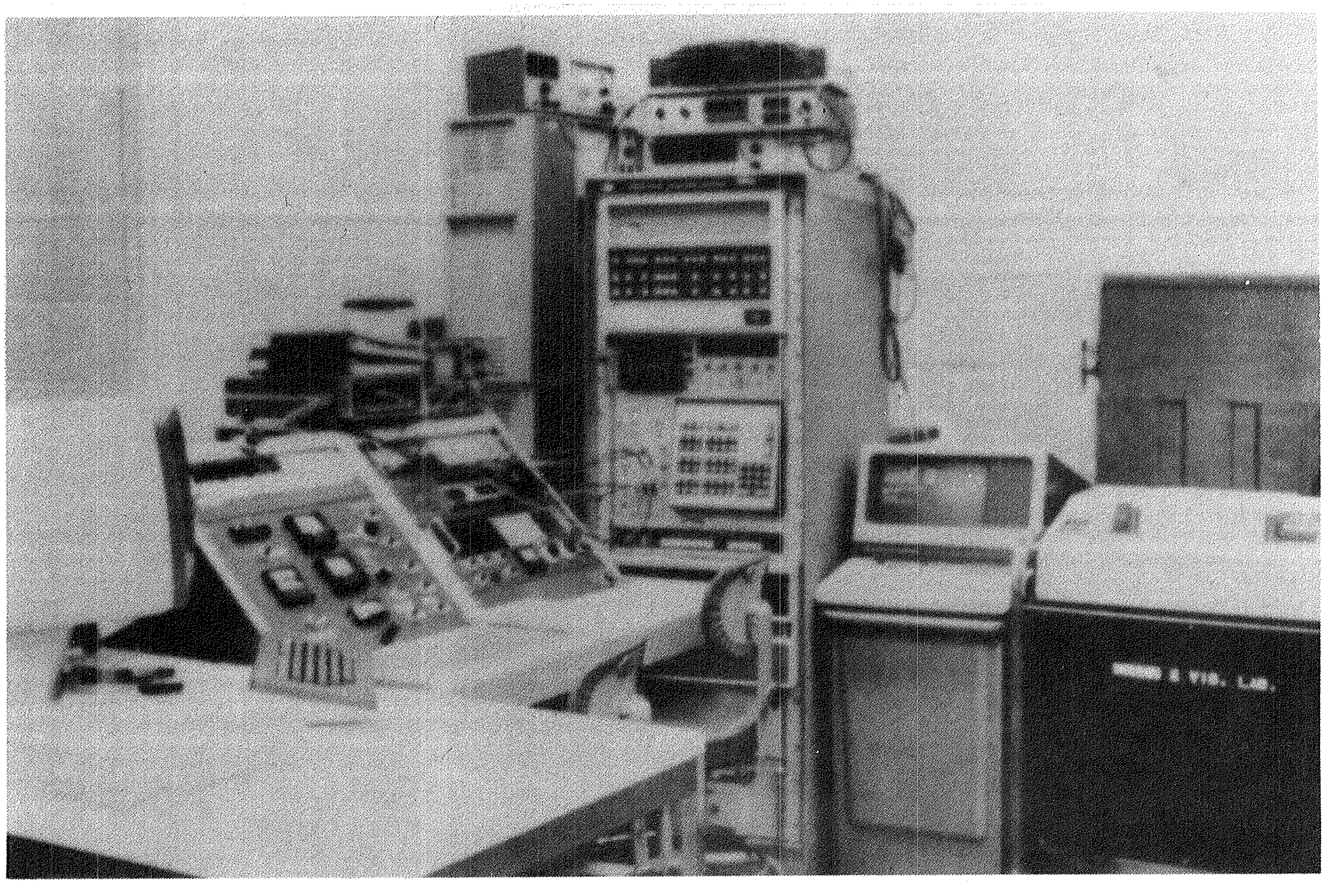


Figure 7 Control and Instrumentation Consoles

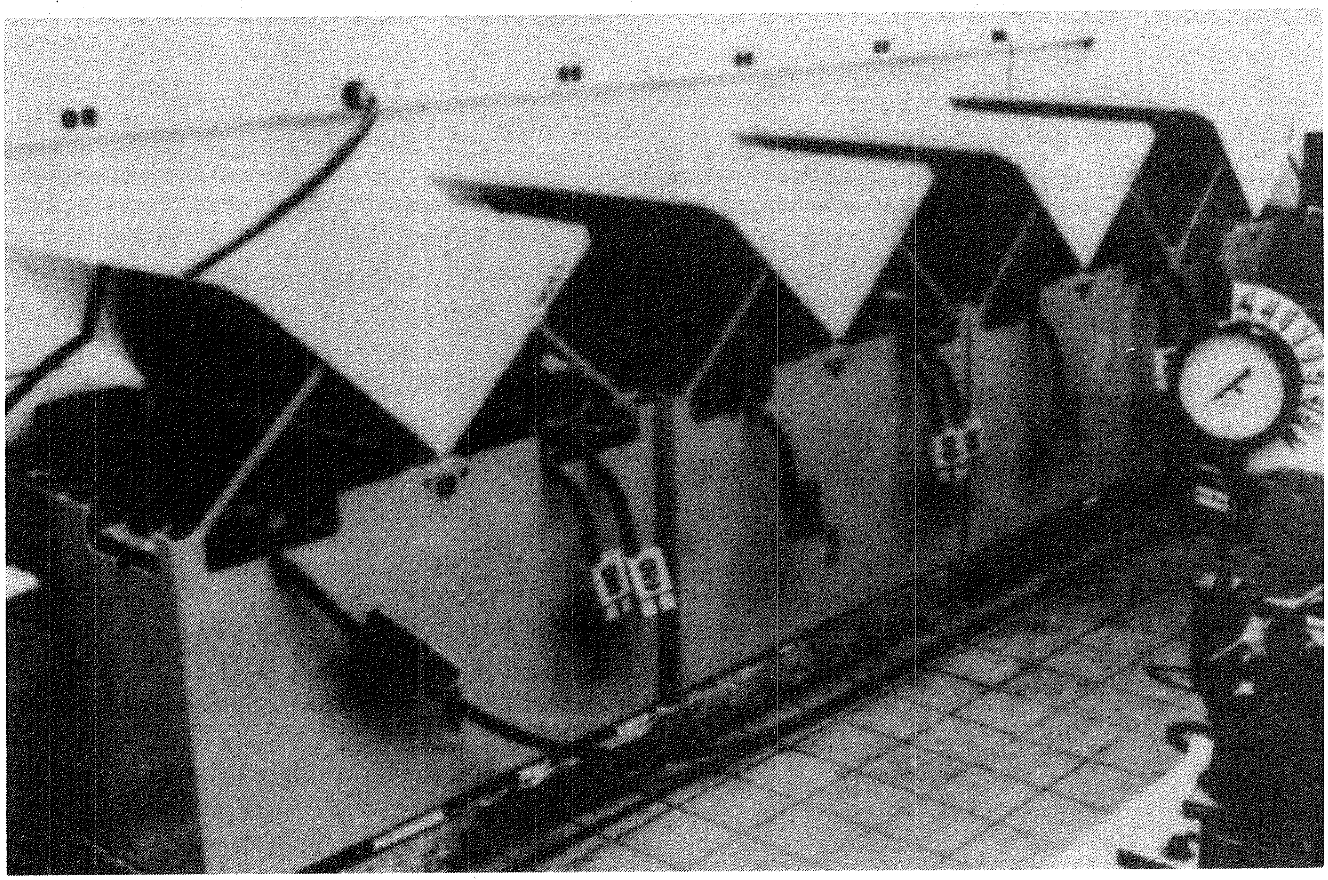


Figure 8 Battery Power Supply

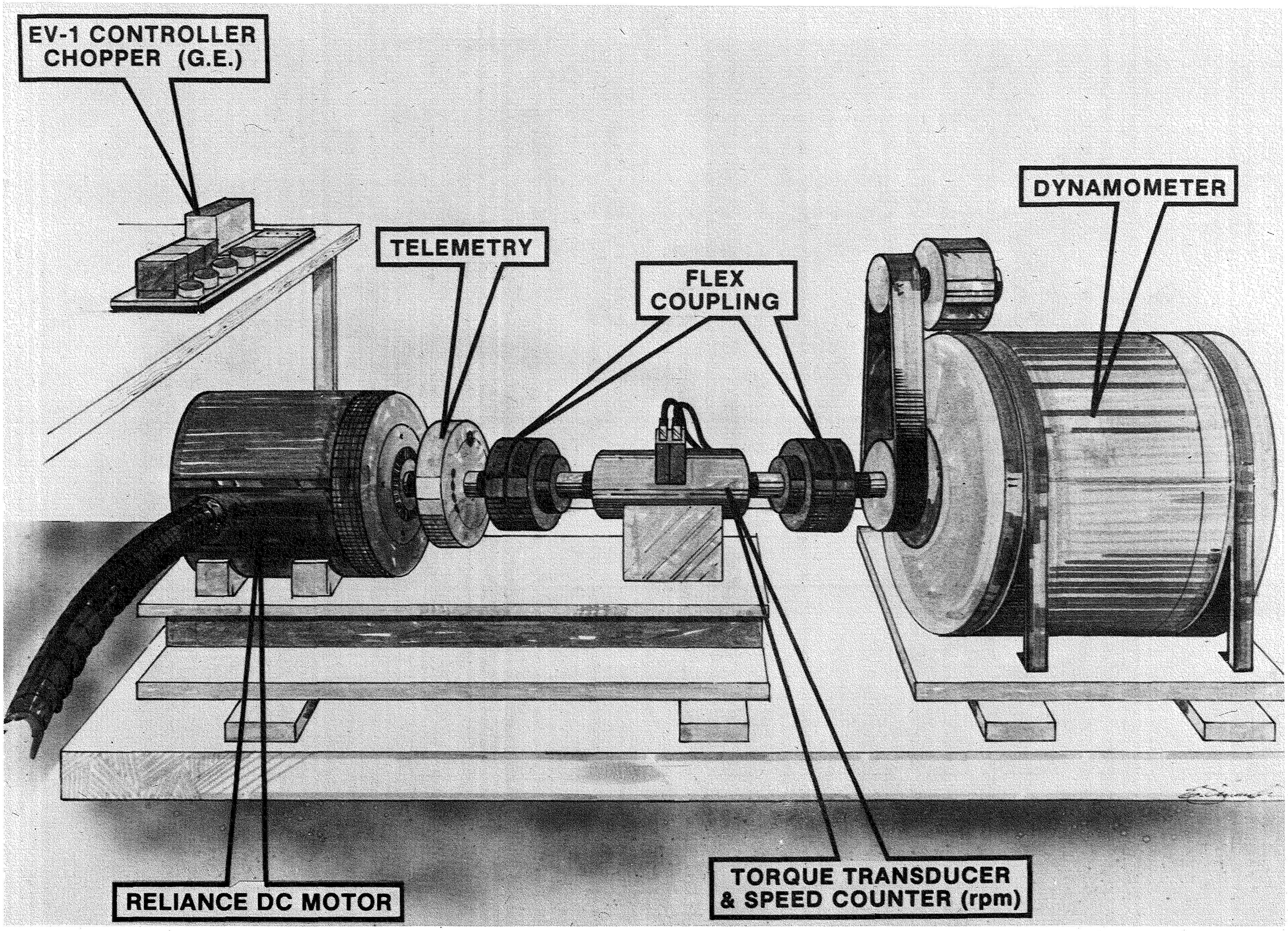


Figure 9 Motor Mounting and Transducer Configuration

The motor was cooled, when necessary to maintain temperature within the specified limits, by a squirrel cage blower motor forcing air through the motor's cooling duct. Room air was also forced over the motor housing using a conventional fan. Motor and controller operator controls were located on the dynamometer console. These included motor power and controller power switches and controller acceleration potentiometer. Safety systems for the dynamometer also served to shut off the motor/controller in event of an unsafe condition. A 300 amp DC contactor, controlled at the console, switched battery power to the motor. When data was taken for chopped DC operation, power was routed through a resistive load in series with the battery to simulate a more realistic source impedance, as would be found in a typical electric vehicle. This resistance had a value of 0.059 ohm, and was capable of dissipating approximately 5200 watts.

4. Instrumentation

Connection between the motor and dynamometer was made via a Lebow type 1604-2K torque-speed transducer. The torque transducer was of the rotary transformer type; the speed transducer was of the magnetic pickup type. Full-scale ranges were 225 N-m (2000 in-lbs) for the torque and 15,000 rpm for the speed pickup.

Also coupled directly to the motor was an Inmet Model 201A temperature telemeter. Two type T thermocouples were mounted on the motor armature laminations, 180 degrees apart. Thermocouple wire was run underneath the motor bearings, through the shaft keyway (which was extended for this purpose) and directly to the telemeter module. The module and its 9 volt power source were mounted in an aluminum disc 19.0 cm (7.5 inches) in diameter and rotationally balanced to 6000 rpm. A loop antenna was mounted on the small support I-beam to receive the FM transmission. A receiver was located on the control console and calibrated to readout directly in degrees centigrade.

Other temperature measurements were made directly on the field windings, with type K thermocouples. Thermocouple wire was run directly to the control console for readout.

Torque, speed and temperature readout were accomplished using a Daytronics 9000 series modular signal conditioning rack. Readout was directly in SI units. A readout was also provided to calculate motor output horsepower from the speed and torque signals.

Current measurements were made using T&M Research Type F coaxial shunts located on the bench, directly over the motor. These shunts were rated for a 100 mV drop at 200 amps and frequency response of over 0.5 MHz at rated current. Voltage measurements were taken directly from the motor and controller terminals via coaxial cable.

For the straight DC tests, current and voltage measurements were made directly on Fluke Model 8350A digital voltmeters.

For the chopped tests, both the current and voltage signals were fed into Phillips type PM-8940 optical isolators. These units have a frequency response of DC to 1.5 MHz ± 3 dB, with a phase shift of less than 2 degrees at 15 kHz. The isolators serve to amplify (for current measurements) or attenuate (for voltage measurements) the input signal as well as to "float" the inputs, allowing the output signal "commons" to be tied together. The isolator's "front end" is battery powered, completely eliminating any chance for ground loops to be created on the signal lines.

Since it was necessary to measure average and RMS voltages and currents, as well as average wideband power for the chopped DC tests, a Hewlett-Packard 5451B Signature Analysis System was utilized.

Output signals from the isolators were fed directly into the Hewlett Packard system. Analog-to-digital converters sampled the data at 20,000 points/sec., and digitally performed the calculations for average, RMS and power measurements.

The analyzer was programmed to print out all data required for each test point automatically. To assure waveform integrity, data from each channel was constantly monitored on an oscilloscope while being input to the analyzer.

TEST PROCEDURES

1. Test Sequence

A typical test run consisted of initially assuring the motor to be at the correct test temperature. Two temperature ranges were tested, 25°-45°C and 130°-150°C. For the high temperature runs, this was accomplished by operating the motor with the frame wrapped with layers of fiberglass insulation. Once the desired temperature range had been reached, the motor was driven up in speed with the field supply set at the desired current level. When the voltage level generated by the motor armature matched the desired motor operating voltage, the main contactor was closed supplying power from the batteries to the motor. This resulted in near "zero torque" data point, at which data was recorded. once completed, the motor was slowed by a small increment (the magnitude depending on the particular field current being supplied) for a second data point. This procedure continued until the torque transducer limit was reached. When the motor heated above its testing temperature range, forced air blowers were turned on, allowing it to cool. Once the maximum torque point had been taken, the motor was brought back to maximum speed at identical increments to record motor hysteresis. When completed, the next voltage tap was selected, and tested as before. Six motor input voltage levels were selected: 16, 24, 36, 64, 80, and 96 volts. Four values of field current were also selected at 9, 6, 3, and 2.3 amperes. When all required input voltages were tested, the entire procedure was repeated a total of 3 times. The procedure was followed for both ripple-free and chopped testing, the only difference being that for the chopped data, motor input voltage was controlled by adjusting the chopper acceleration potentiometer to achieve the proper level. Chopped data was taken at a 96-volt level to the controller. It was discovered that, during motor operation, a high value of duty cycle from the controller would cause instability. To improve this condition, a series choke was added at the output of the chopper to the armature. This choke was rated at 1.0 mh at 0.011 ohms. While this greatly improved stability, operating at extremely high values of duty cycle was still not possible. Thus, the chopped data was not taken at the 96-volt input level to the motor. The internal IR drop of the choke also limited the amount of data possible at the 80-volt level, before the average value of voltage to the motor fell off. Battery condition was constantly monitored to assure that excessive "droop" was not occurring due to lack of charge level. For the resulting data, "droop" in input voltage level is primarily due to interconnecting cable IR drop, inter-battery connection IR drop, and for chopped data only, the IR drop due to the series 0.059 ohm added resistance, and series choke.

2. Data Acquisition

Data which was directly read from instruments and the Hewlett Packard analyzer printout was typed into a portable CRT screen located on the control console. The CRT was tied into the Eaton VAX 11/780 computer, pre-programmed with a "form" format, so that all data was typed under correct headings. This allowed an orderly method of data acquisition, and made it possible to "call up" data from previous runs to compare data points for hysteresis and to assure that there was no substantial data shift from identical earlier tests.

Once in the VAX system, all data from the tests was averaged for each unique test point. This included all three test runs as well as hysteresis points. Averaging was done arithmetically, and was available on hard copy as final test results.

The following parameters have been measured for the motor at each test point:

1. Motor speed - measured at the motor shaft in units of revs./min. (Accuracy, ±1% of 6000 RPM full scale.)

2. Motor torque - measured at the motor shaft in units of Newton-meters. (Accuracy, ±1% of 225 Nm full scale.)

3. Motor temperatures - measured at various points internal to the motor (see section titled "Instrumentation" for details) in units of degrees centigrade. (Accuracy, ±0.4°C for field measurements, ±2°C for armature measurements.)

4. Motor input voltage - measured at the input terminals of the motor in units of volts. (Accuracy, ±0.01% of 199 volt full scale.)

5. Motor input current - measured at the input terminals of the motor in units of amperes. (Accuracy, ±0.50% of 400 ampere full scale.)

6. Controller input voltage - measured at the input terminals to the controller in units of volts. (Accuracy, ±1% of 200 volt full scale.)

7. Controller input current - measured at the input terminals to the controller in units of amperes. (Accuracy, ±1% of 400 ampere full scale.)

8. Controller input power - measured at the input terminals to the controller in units of watts. (Accuracy, ±2% of 80,000 watt full scale.)

9. Controller output voltage - measured at the output terminals of the controller in units of volts. (Accuracy, ±1% of 200 volt full scale.)

10. Controller output current - measured at the output terminals of the controller in units of amperes. (Accuracy, ±1% of 400 ampere full scale.)

11. Controller output power - measured at the output terminals of the controller in units of watts. (Accuracy, ±2% of 80,000 watt full scale.)

(Measurements #1-#3 were made for all tests, measurements #4 and #5 for straight DC tests, and measurements #6-#11 for chopped DC tests.)

TEST RESULTS

The test results are tabulated in Tables 1 through 10 and depicted graphically in Figures 10 through 21. As indicated in the "Test Procedures" Section of this report, three separate test runs were made at each test condition. Each run started at "zero torque" speed. The motor was gradually loaded, and data was taken at the speeds indicated in the tables until maximum load was achieved. The load was then gradually removed, and data was again taken at the same speeds. Consequently, the original test data consists of six data points at each speed and each test condition. This data was averaged and reduced to decrease the data scatter and the volume of test data to be reported.

1. Data Reduction

The original intent of running three test points with speed decreasing and three test points with speed increasing was to show the effect of hysteresis on the motor performance. However, the hysteresis effects were found to be negligible, so all six data points were averaged together.

For tests of a motor that will be used with a specified power source, the input voltage is usually varied in accordance with the power supply characteristics. Where the power source is not specified, the input voltage is usually held constant.

For the straight DC tests, constant voltage data was desired. Since the input voltage varied somewhat, a correction factor was applied to the speed data. This compensation factor considered the internal copper I_A R_A drop of the motor but did not include an allowance for brush drop. The following compensation equation was used:

$$\text{compensated speed} = \text{test speed} \left(\frac{V_{IDEAL} - R_A I_A}{V_{TEST} - R_A I_A} \right)$$

0.01596 ohms was used for the value of R_A. The new compensated speed was used in all subsequent calculations such as motor output, power, and efficiency. The curves were also plotted using the compensated speed or the compensated power output as a parameter.

For the chopped DC tests, it appeared to be more appropriate to try to simulate the voltage "droop" characteristics of presently available electric vehicle batteries. At each test point, the controller was adjusted to maintain a nearly constant value of average motor voltage; thus, speed conpensation is not necessary.

Once the data was averaged, a best fit plotting routine was utilized on the VAX to produce the following plots:

1. Torque - speed (for each voltage level)
2. Power - speed (for each voltage level)
3. Torque - current (for all voltage levels)

At this time, plots of efficiency-speed were derived by the following process: (for straight DC)

1. Lines of constant power were drawn on the power-speed curves.

2. From these lines, values of speed at each power level for every voltage were extrapolated.

3. Knowing speed and power, torque was calculated for every point.

4. Current was extrapolated for every torque value using the torque current curves.

5. Efficiency for each point was calculated as

$$n = \frac{\text{power out}}{\left(V_{arm} \times I_{arm}\right) + \left(V_{field} \times I_{field}\right)}$$

6. For each line of constant power, the efficiency was plotted against speed using a best fit program.

For the chopped DC data a similar method was used with the following exceptions:

1. Once torque was known for each intersection point, input power to the motor was extrapolated using a torque vs. input power plot (derived for each voltage level from the averaged data).

2. Once derived, efficiency was calculated as

$$n = \frac{\text{power out}}{\text{power in} + \left(V_{field} \times I_{field}\right)}$$

and plotted against speed for each power level using a best fit program.

The final plot of controller efficiency versus volts was derived using the following routine.

1. Equations were calculated for controller efficiency $\left(\frac{\text{power out}}{\text{power in}}\right)$ versus controller output power for each motor input voltage level using each averaged data point.

2. For fixed levels of controller output power, the value of controller efficiency and voltage were stored.

3. Plots were made of controller efficiency-controller output voltage for each power level.

4. Since these plots were overlapping within a narrow range of efficiency (approximately 95%), plots were replaced with a band showing the maximum and minimum extremes of controller efficiency within the power levels indicated.

2. Straight DC Results

The straight DC data for two ranges of temperatures are presented in Tables 1 through 8. The voltage, current, torque, and speed variables are tabulated in the conventional manner. The compensated speed and the compensated power output were calculated as discussed in the Data Reduction Section of this report. The calculated efficiency is the ratio of the compensated power output to the product of the nominal voltage and current.

The temperature tabulations illustrate one of the difficulties in performing this type of testing. Not only does the temperature vary from one point to another in the machine, but the temperature difference also varies.

The tabulated data is depicted graphically in Figures 10 through 17. These curves all have the expected shape.

The data was recorded for two temperature ranges, in order to allow an evaluation of temperature effects. The most discernible temperature effects appear in both the torque-speed and efficiency-speed curves. For the torque-speed plots, the high temperature curves (Figure 11) are shifted slightly to the left of the corresponding low temperature curve. This shift is primarily due to the increase of armature resistance with increased temperature. Since the torque-current curves are in close agreement, a given torque will produce a greater $I_A R_A$ voltage drop at the higher temperature. Consequently, the counter electromotive force and speed will decrease.

For the efficiency-speed curves, the high temperature efficiency of the motor is less than the low temperature efficiency for a given output power level. Peak efficiency appears at moderate loads, reasonably high speeds, and maximum voltage. The efficiency drops below 75% only at light loads or low voltage levels.

As field is weakened, the motor base speed increases for a given armature voltage, and the curves continue to appear as expected. As the field current decreases, the torque-speed curves begin to become less linear. Motor efficiency, as shown in Tables 2, 3, 4, 6, 7, and 8, maintains approximately the same maximum level as for the full field data at similar operating temperatures.

3. Chopped DC Results

The chopped DC data are tabulated in two categories as follows:

Table 9	25-45°C	96 Volt Input
Table 10	130-150°C	96 Volt Input

This data is also depicted graphically in Figures 18-21.

The voltages refer to the nominal input voltages to the chopper.

Both the average and the root mean square (RMS) values of all the voltages and currents were recorded. Only the average values of the variables were used to generate the curves depicted in Figures 18 through 21. The RMS values were recorded to give an indication of the form factor of each variable and to aid in future modeling work. The duty cycle of the controller may roughly be considered to be the ratio of the average value of the chopper output voltage to the average value of the chopper input voltage.

A comparison of the chopper input power wattmeter reading with the product of the average input voltage and current value will indicate that sizeable errors may result by using the volt-amp product as a measure of power. For the low voltage tests, the product of the average values of voltage and current is greater than the wattmeter reading. However, at high values of test voltage the volt-amp product is less than the wattmeter reading. (The deviation at high test voltage is approximately 3%, and may be attributed to instrumentation error.) The product of the RMS values of voltage and current are always greater than the wattmeter reading.

The maximum values of motor efficiency for the chopped DC case approached the maximum values for the straight DC case. These maximum efficiency values all occur at or near maximum voltage and correspond to duty cycles near 100%. Consequently, they should be expected to approach the straight DC values. However, the chopped efficiency levels never match the straight DC levels, due to the lack of system stability at 100% chopper duty cycles. At low duty cycles the efficiency may be considerably less than the efficiency for straight DC.

The measured chopper efficiency is about 95% throughout the test range. Small errors in either chopper input or output power measurement result in variations in the calculated chopper efficiency. Consequently, the variations observed at individual test points are not significant.

A comparison of the chopped DC torque versus speed curves with the corresponding straight DC curves shows that the chopped DC curves are shifted slightly upward and to the right. For equal speeds, the additional torque produced in the chopped mode is due to the AC component in both the current and flux waves.

The torque-speed curves for the chopped mode of operation (Figures 18A and 20A) show that the curve for maximum voltage approaches the next lower voltage curve for high values of torque. This phenomenon is caused by the impedance of the power source and series choke. The corresponding tabulated data shows that for the highest voltage curve in each category,

the chopper duty cycle approaches 100% and that a constant voltage cannot be maintained at the chopper output terminals as torque is increased. As the highest voltage curve approaches the region of coincidence with the second highest voltage curve, the chopper duty cycle is also near 100% for the second highest curve.

CONCLUSIONS

A fairly elaborate setup is required to perform the tests described in this report.

1. Power Supply Requirements

   Ideally the motor should be tested with the specific power supply with which it will be used. In the case of battery powered vehicles, the variations of battery characteristics and its limited energy capacity make actual vehicle batteries impractical. Some compromises must be made. In the straight DC mode of operation, a constant voltage source appears to be most desirable. In the chopped mode, the internal impedance of the source substantially affects wave shapes.

2. Temperature Control

   The temperature of the motor windings can change very rapidly. To expedite testing, the winding temperatures should be monitored and some method of heating and cooling the motor is desirable.

3. Instrumentation

   For the chopped mode of operation, the instrumentation must be carefully considered. Significant errors can result from using the product of voltage and current as an indicator of power. Suitable wattmeters must be used. Many readings will be a small fraction of full scale and accuracy may be less than expected.

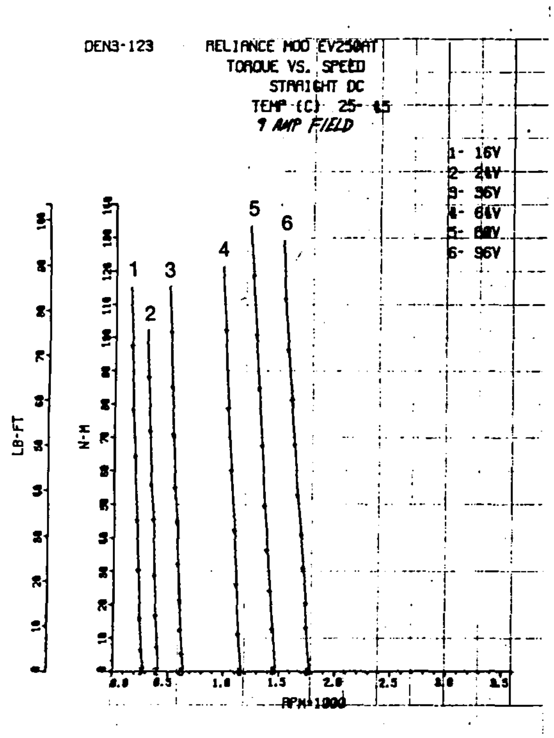
4. Test Results

   a. The controller efficiency may be assumed to be about 95% throughout the test range.

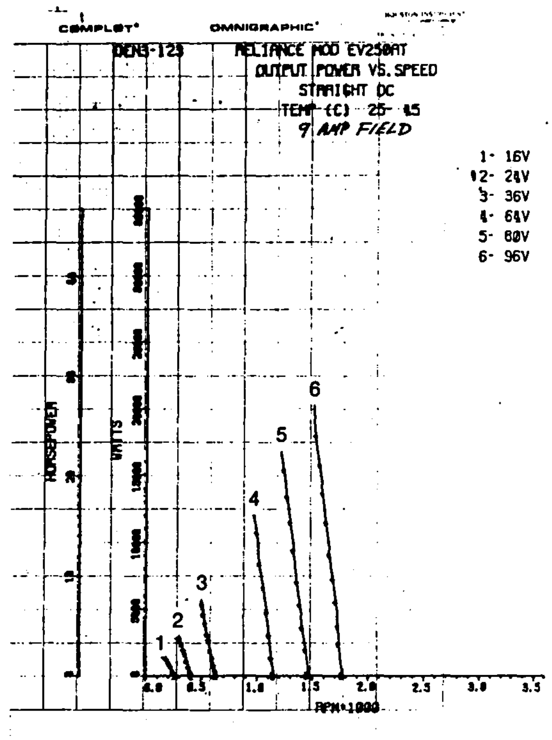
   b. The maximum efficiency of the motor was approximately 85% at low operating temperatures in the straight DC mode. However, at low chopper duty cycles the motor efficiency may be considerably less than it is on straight DC.

   c. Most of the variations caused by changing test conditions are discernable on conventional torque-speed curves. For equal torque, a motor at high temperature will run somewhat slower than the same motor at a lower temperature. For equal speeds, a motor operated in the chopped mode develops slightly more torque than it does in the straight DC mode.

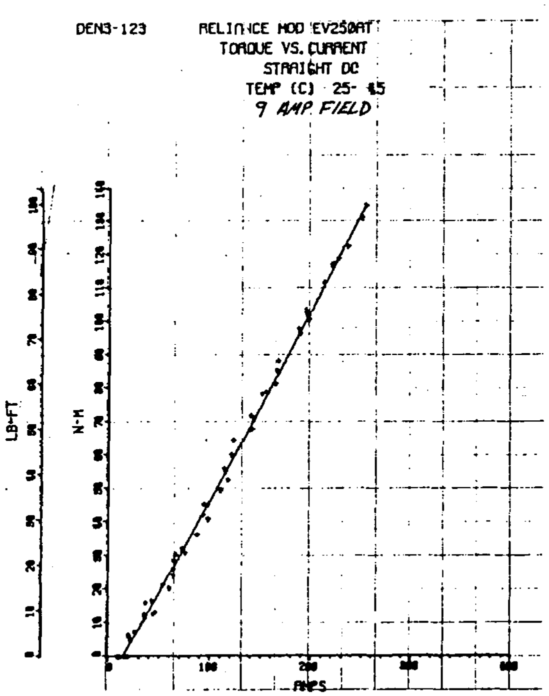
   d. The hysteresis effects of the motor alone, as well as the motor-controller combination, are negligible and can be ignored.



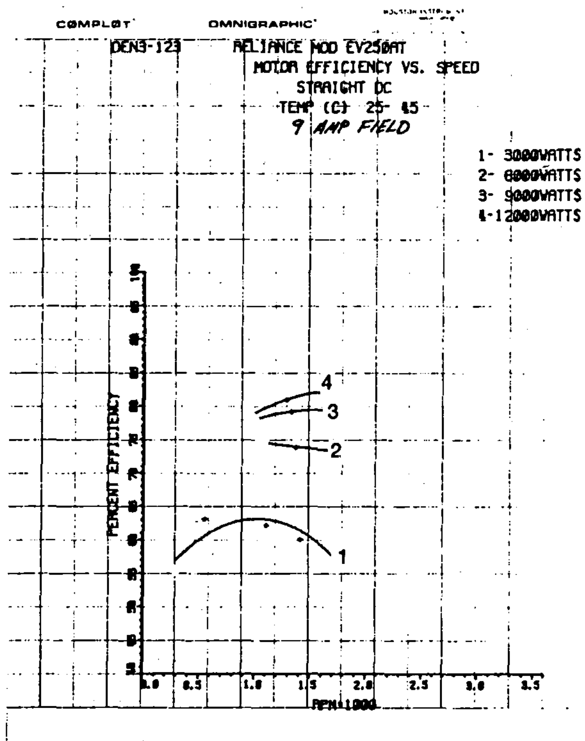
A. Speed - Torque Characteristics



B. Output Power Characteristics

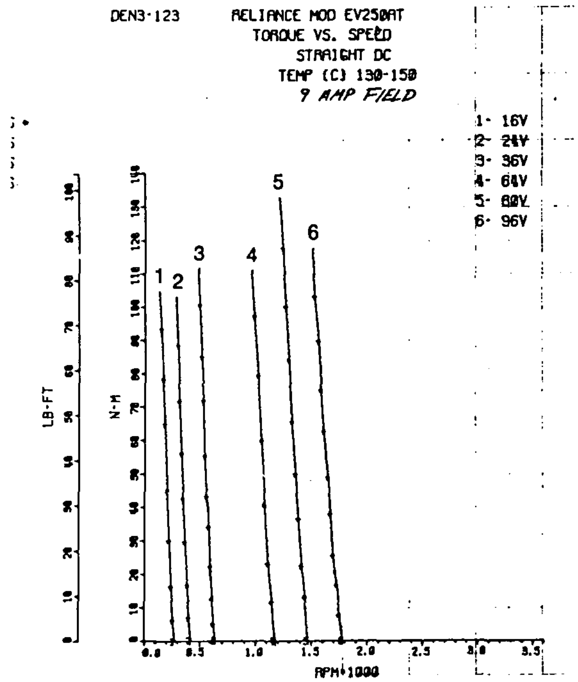


C. Torque - Current Characteristics

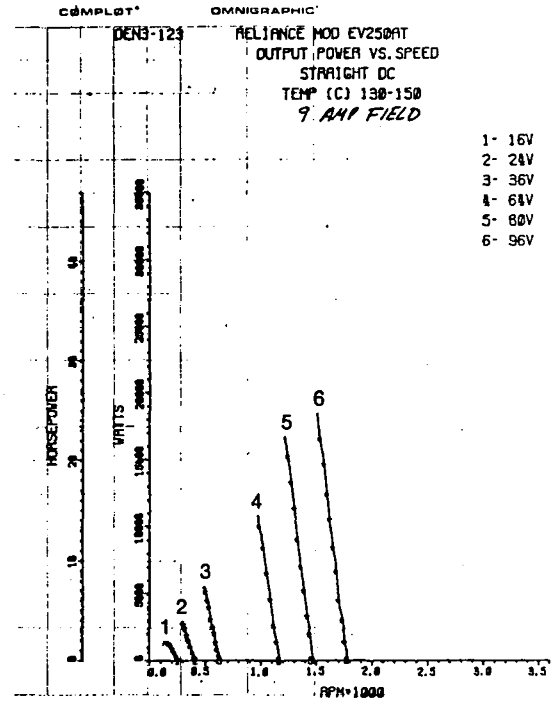


D. Efficiency - Speed - Power Relationships

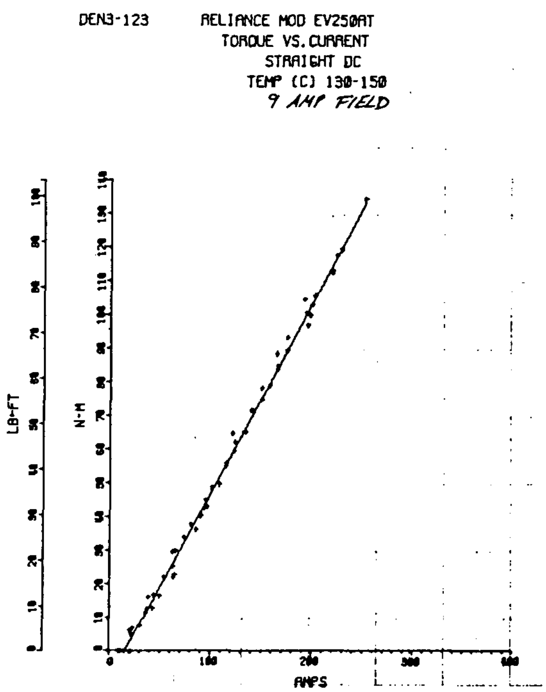
Figure 10 Low Temperature - Full Field - Straight DC



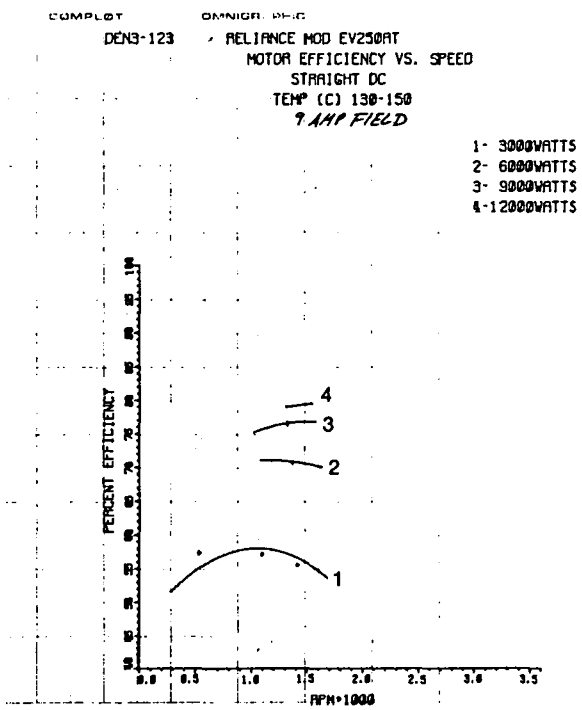
A. Speed - Torque Characteristics



B. Output Power - Speed Characteristics

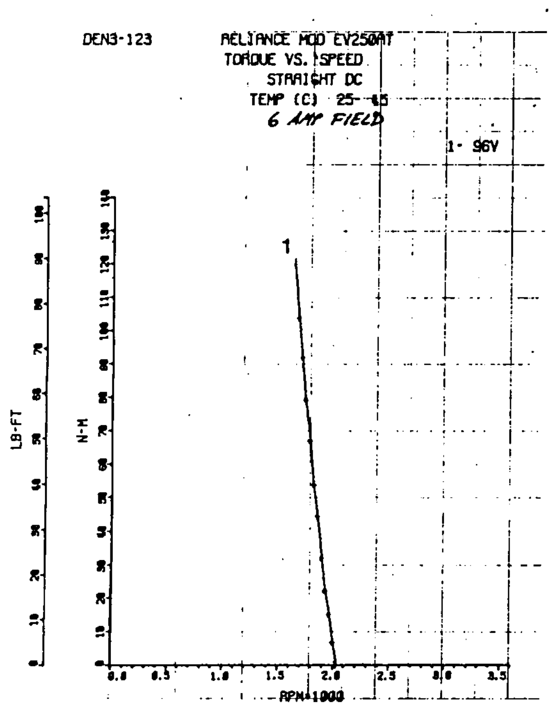


C. Torque - Current Characteristics

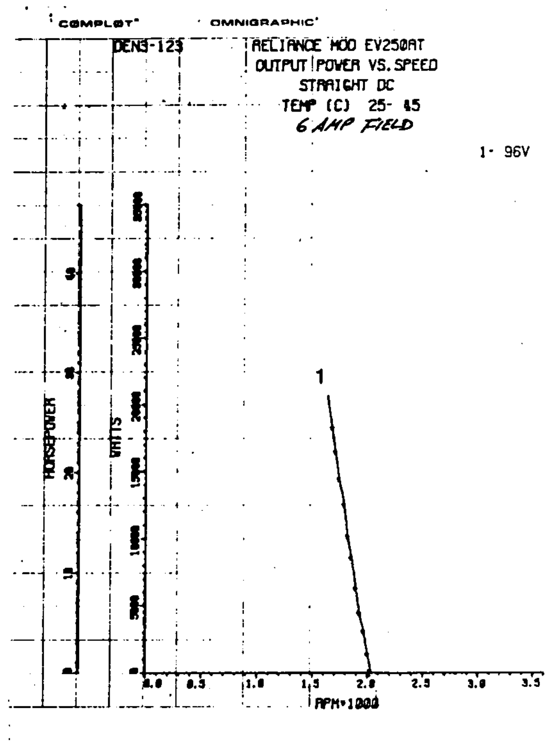


D. Efficiency - Speed - Power Relationships

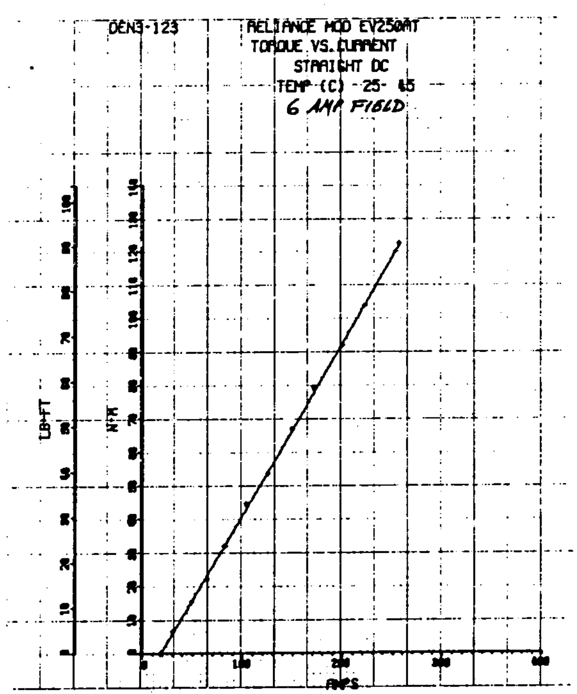
Figure 11 High Temperature - Straight DC - Full Field



A. Speed - Torque Characteristics

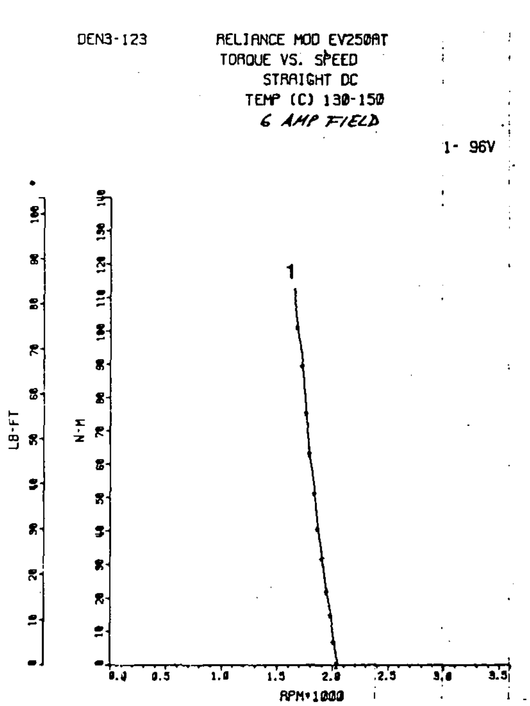


B. Output Power - Speed Characteristics

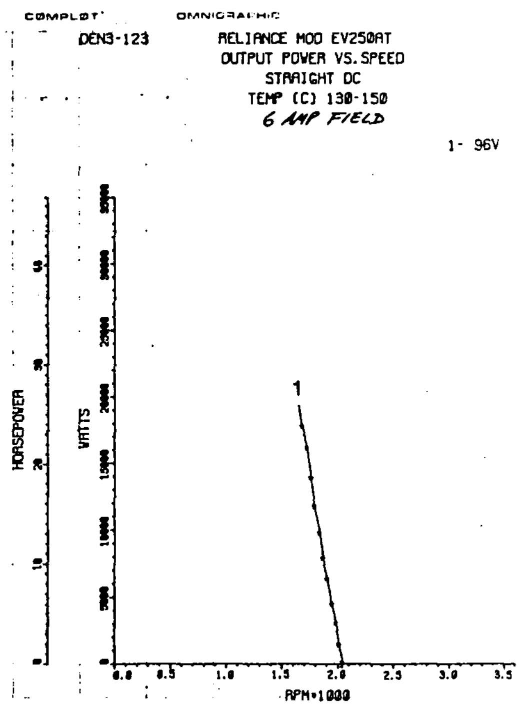


C. Torque - Current Characteristics

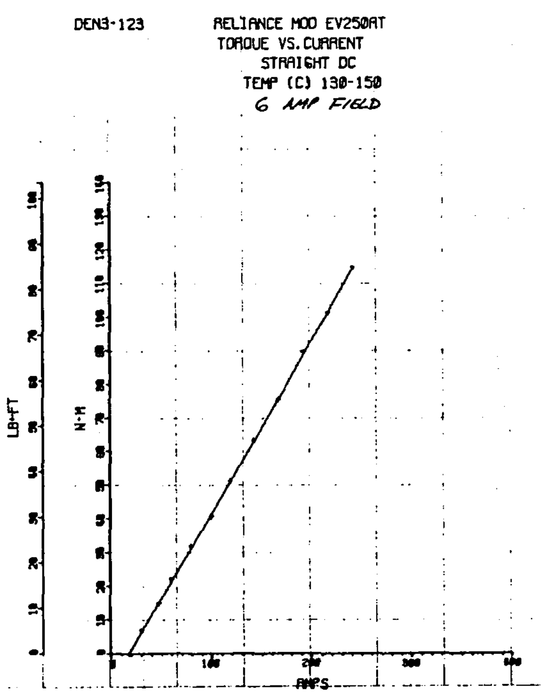
Figure 12 Low Temperature - Straight DC - 6 AMP Field



A. Speed - Torque Characteristics

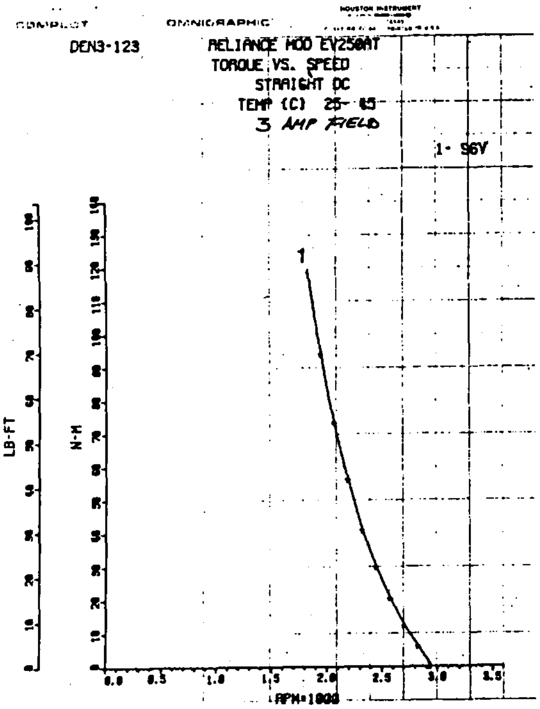


B. Output Power - Speed Characteristics

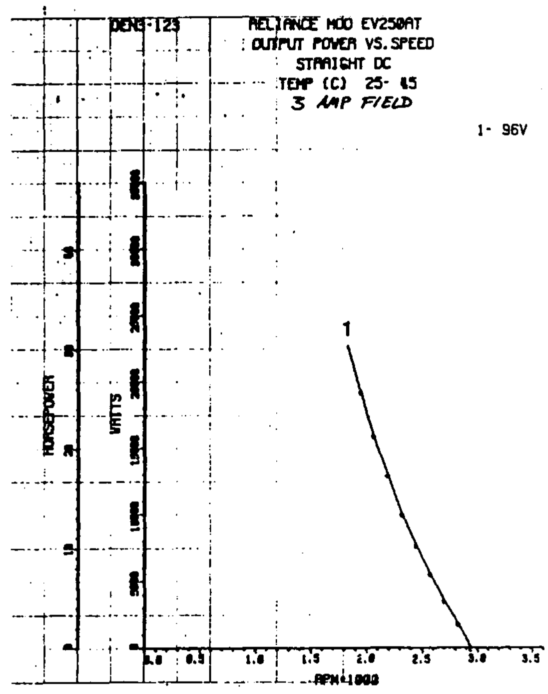


C. Torque - Current Characteristics

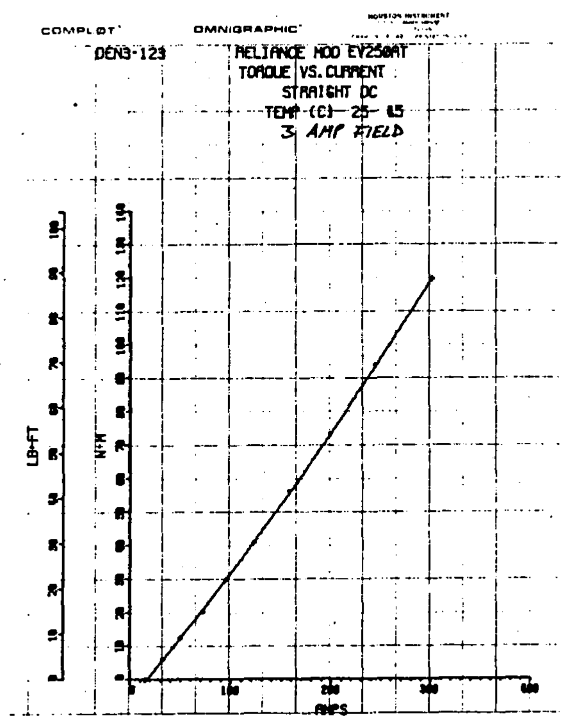
Figure 13 High Temperature - Straight DC - 6 AMP Field



A. Speed - Torque Characteristics

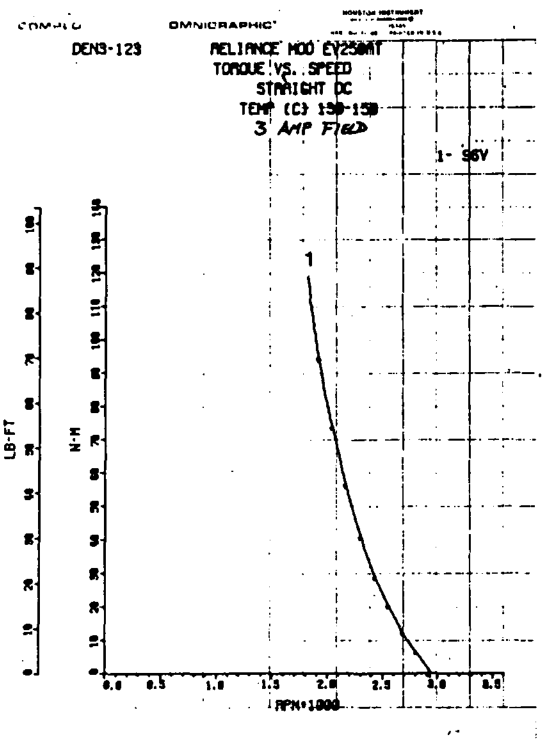


B. Output Power - Speed Characteristics

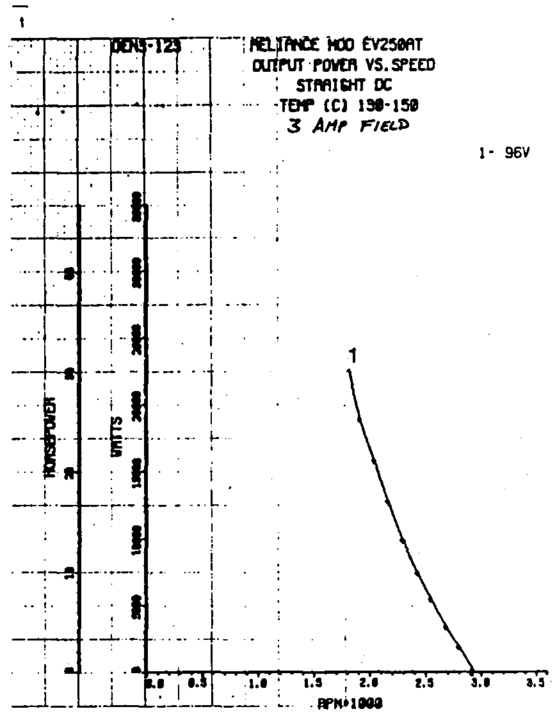


C. Torque - Current Characteristics

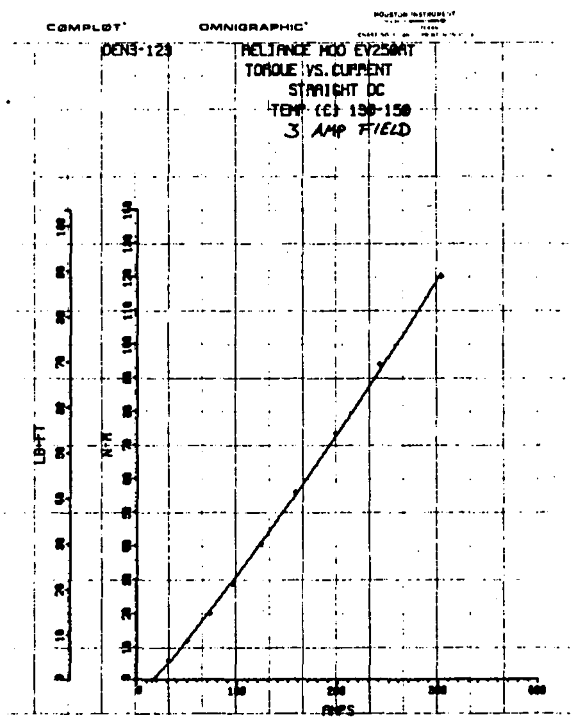
Figure 14 Low Temperature - Straight DC - 3 AMP Field



A. Speed - Torque Characteristics

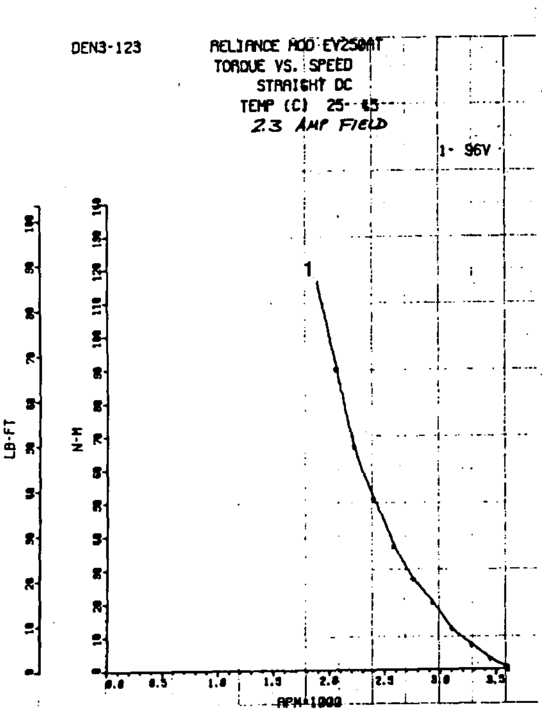


B. Output Power - Speed Characteristics

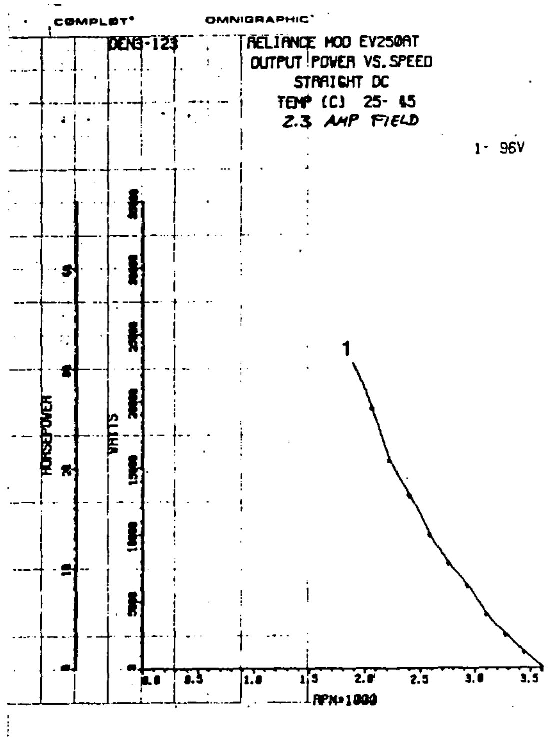


C. Torque - Current Characteristics

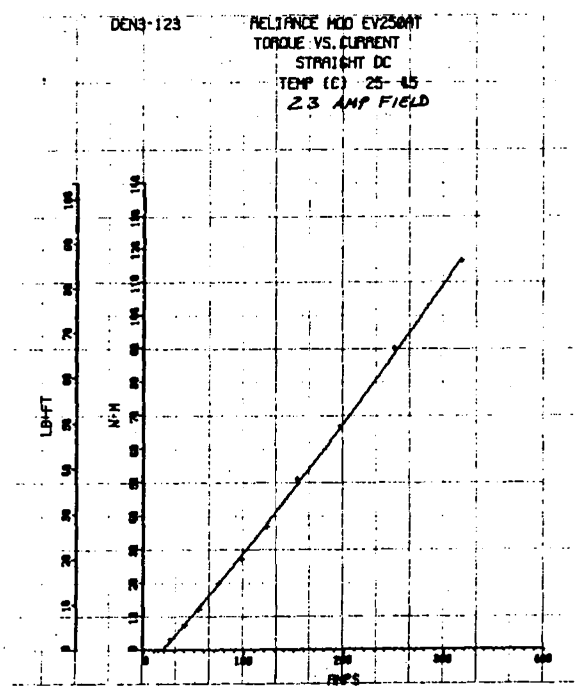
Figure 15 High Temperature - Straight DC - 3 AMP Field



A. Speed - Torque Characteristics

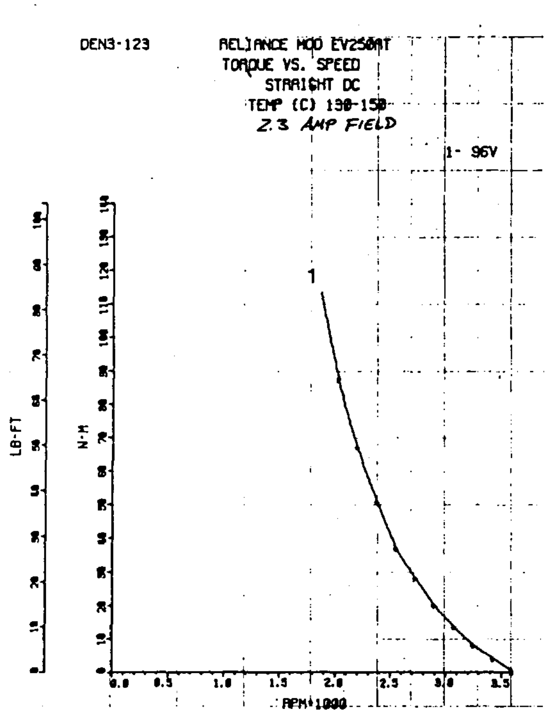


B. Output Power - Speed Characteristics

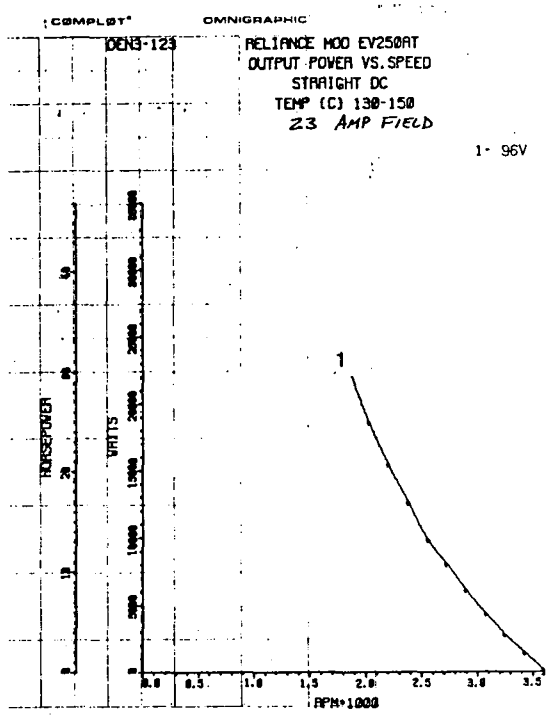


C. Torque - Current Characteristics

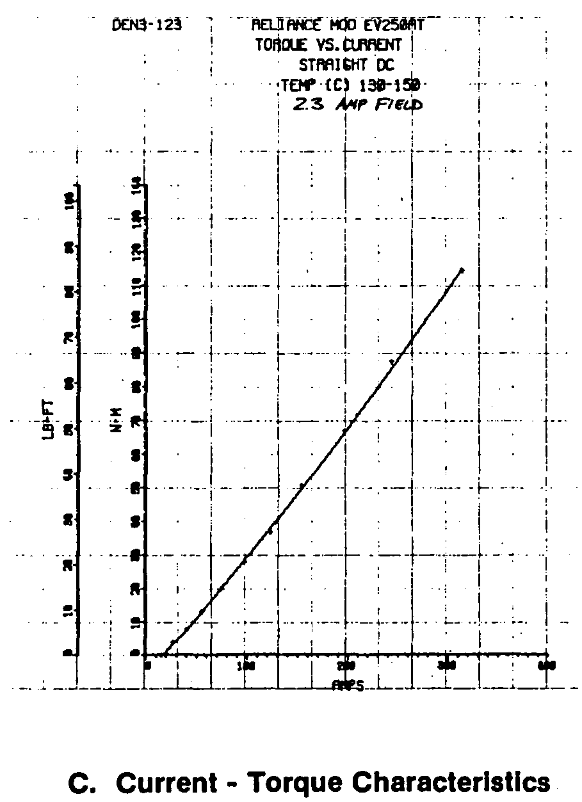
Figure 16 Low Temperature - Straight DC - 2.3 AMP Field



A. Speed - Torque Characteristics

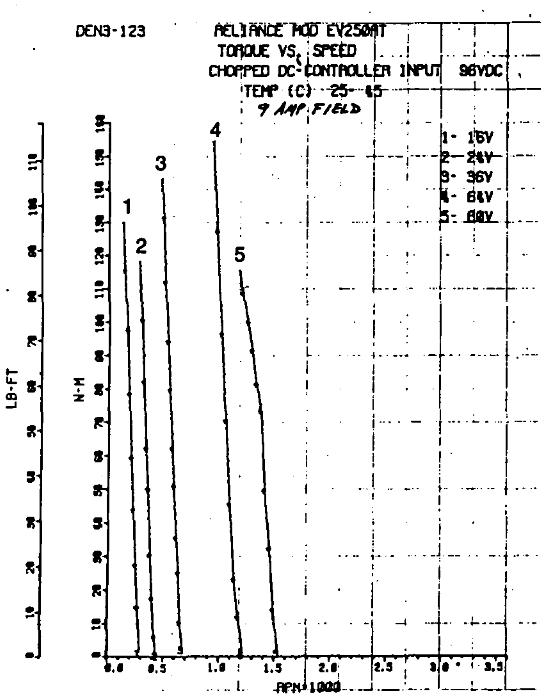


B. Output Power - Speed Characteristics

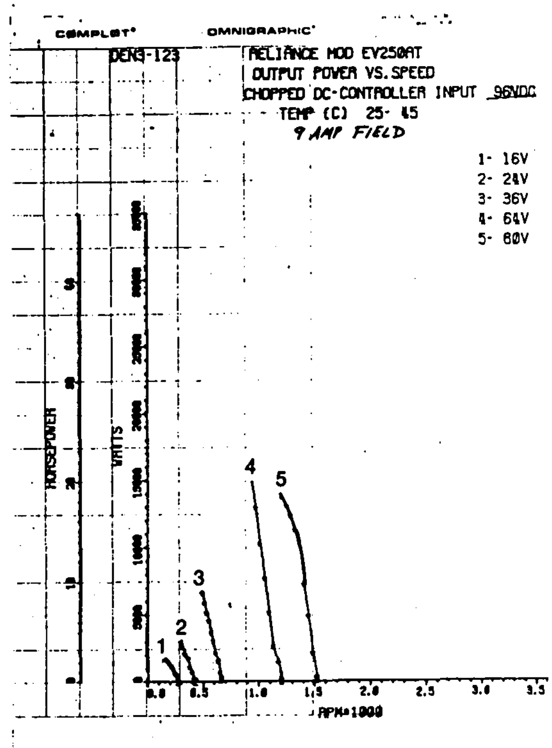


C. Current - Torque Characteristics

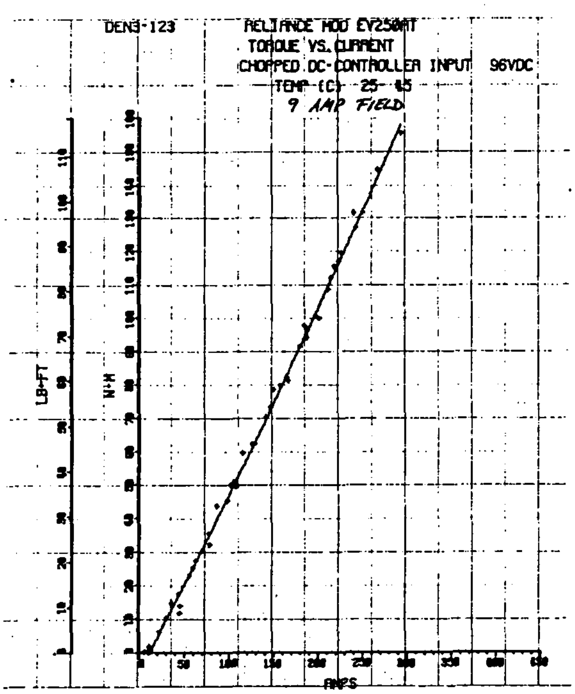
Figure 17 High Temperature - Straight DC - 2.3 AMP Field



A. Speed - Torque Characteristics

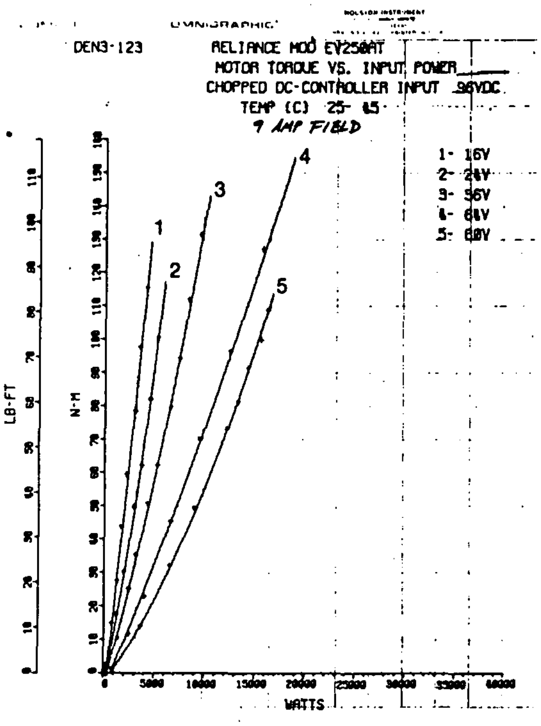


B. Output Power - Speed Characteristics

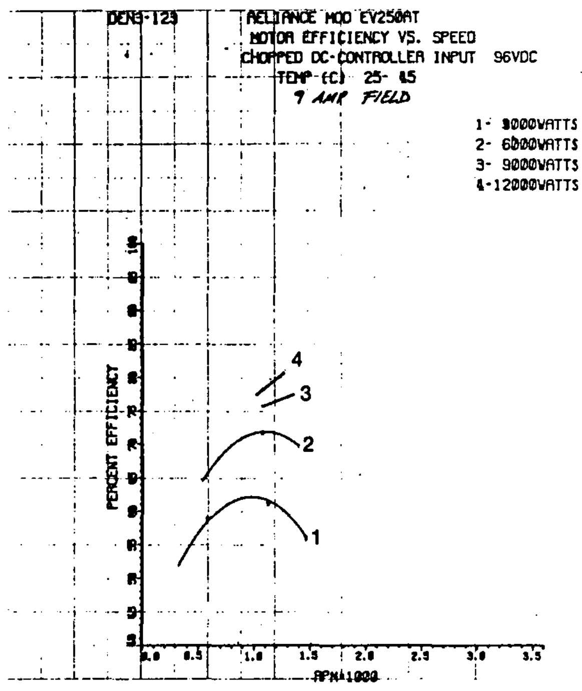


C. Torque - Current Characteristics

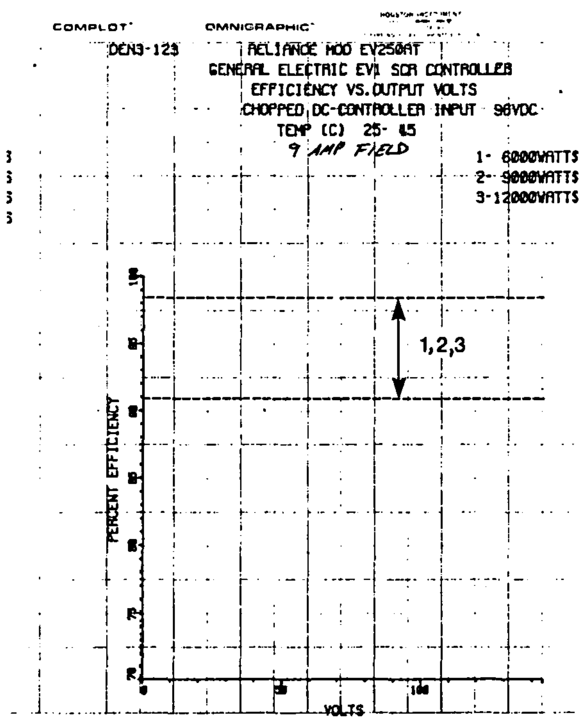
Figure 18 Low Temperature - Chopped DC - Full Field



A. Torque - Power - Voltage Relationships

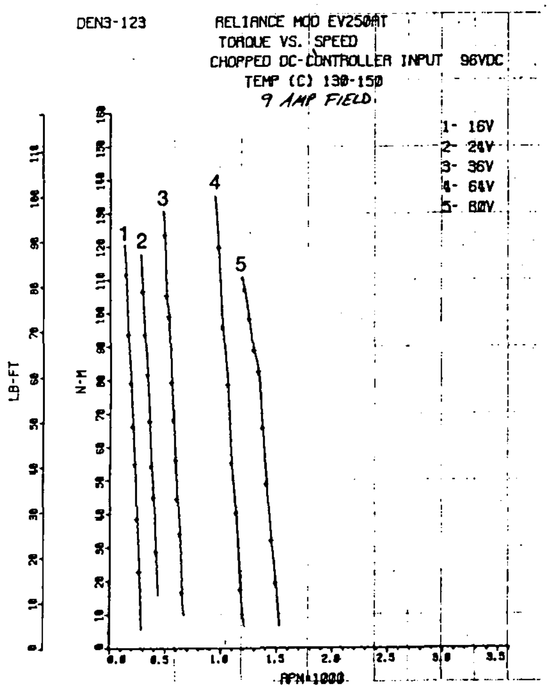


B. Motor Efficiency - Speed - Power Relationships

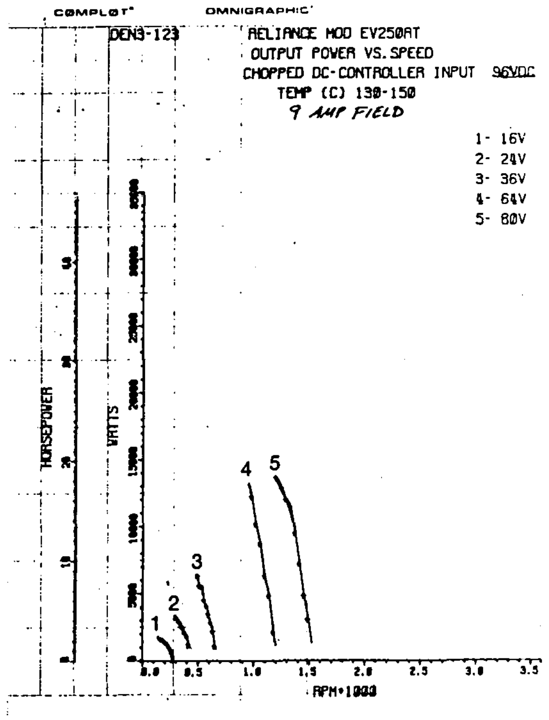


C. Controller Efficiency

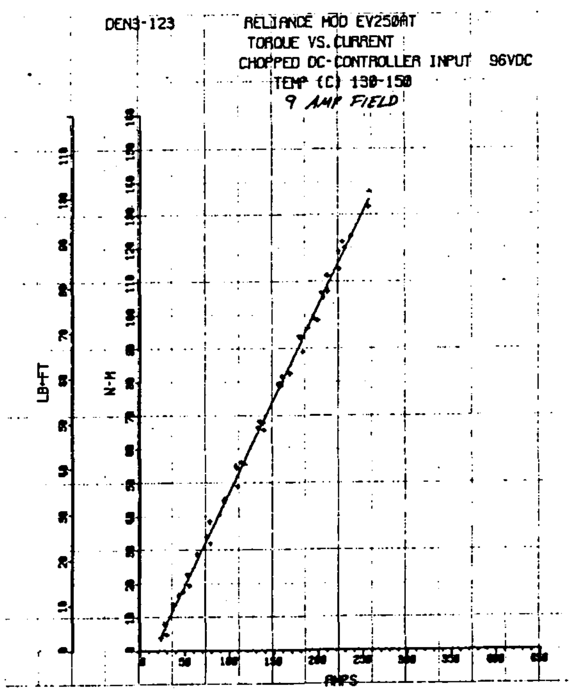
Figure 19 Low Temperature - Chopped DC - Full Field



A. Speed - Torque Characteristics

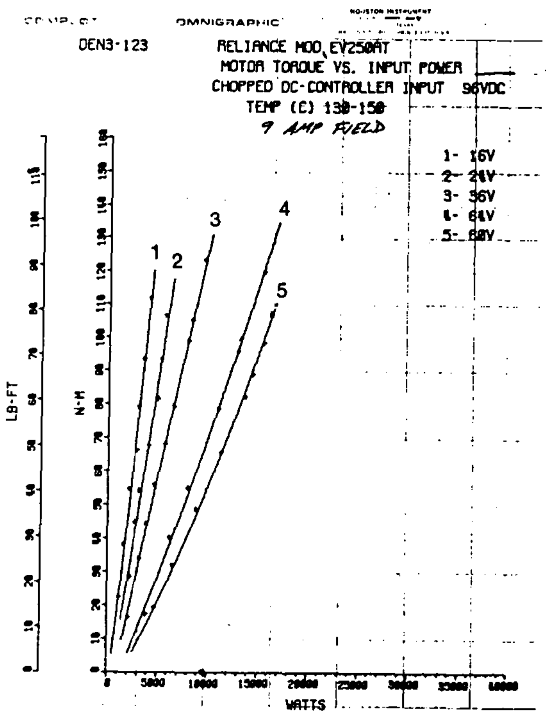


B. Output Power - Speed Characteristics

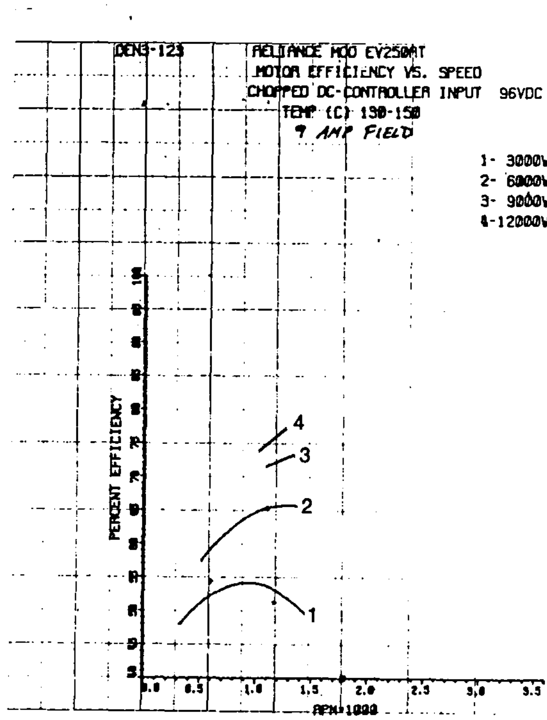


C. Torque - Current Characteristics

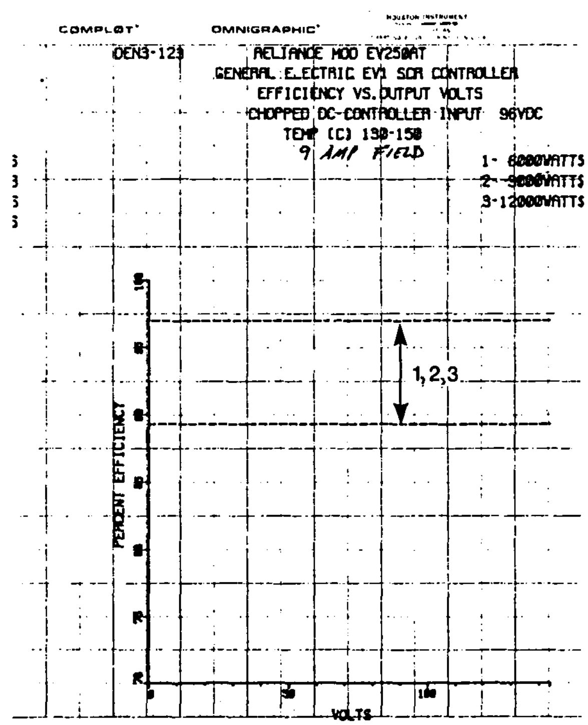
Figure 20 High Temperature - Chopped DC - Full Field



A. Torque - Power - Voltage Relationship



B. Motor Efficiency - Speed - Power Relationships



C. Controller Efficiency - Full Field

Figure 21 High Temperature - Chopped DC - Full Field

TABULAR DATA

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TABLE 1

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 9A @90V = 810 WATTS)

RELIANCE (9 AMP FIELD) STRAIGHT DC TESTS, 25-45^{o}C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (^{o}C) #1	MOTOR FIELD TEMP (^{o}C) #2	MOTOR ARMATURE TEMP (^{o}C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
16	31	31	31	16.7	9.9	0.1	285	273.5	2.9	0.2
	31	31	31	16.6	20.6	6.5	265	255.5	174.0	15.3
	31	31	31	16.3	37.6	16.1	245	239.8	404.9	28.7
	32	31	31	16.2	66.9	30.5	225	222.8	711.9	37.9
	32	32	32	16.0	94.5	45.3	205	204.8	982.7	42.3
	32	32	32	15.8	123.2	64.4	185	188.1	1269.1	45.6
	33	33	33	15.6	151.7	78.3	165	169.8	1392.9	43.0
	34	33	33	15.4	188.0	97.7	145	152.6	1562.0	40.9
	33	33	34	15.0	221.2	116.9	125	136.3	1669.3	38.4
24	31	31	30	25.4	11.6	0.1	435	410.8	4.3	0.4
	33	33	31	25.0	26.7	7.4	415	398.9	309.3	21.3
	34	34	32	24.8	43.3	16.8	395	382.2	672.7	36.4
	34	34	33	24.4	65.0	28.8	375	367.5	1108.9	46.8
	35	34	33	24.2	94.6	45.4	355	352.4	1676.2	54.4
	35	35	33	23.9	114.6	55.9	335	337.0	1973.7	55.4
	34	34	31	23.6	140.3	71.9	315	320.6	2415.1	57.8
	35	35	31	23.4	167.4	88.1	295	303.5	2801.4	58.0
	36	36	32	23.2	194.9	103.4	275	285.5	3092.9	56.4
36	34	34	33	38.0	13.3	0.0	670	635.1	0.0	0.0
	34	33	33	37.6	22.8	5.4	650	622.1	352.0	21.7
	35	35	34	37.2	36.1	12.6	630	608.8	803.7	38.1
	36	36	35	36.8	54.4	21.3	610	596.7	1331.6	48.1
	37	36	36	36.7	73.4	32.2	590	578.9	1953.0	56.6
	37	36	36	36.3	97.3	45.0	570	565.1	2664.2	61.8
	37	37	36	36.0	115.6	55.0	550	549.7	3167.5	63.7
	37	37	37	35.8	143.2	71.0	530	534.0	3972.2	66.6
	38	38	37	35.6	166.4	85.3	510	516.7	4617.7	67.9
	38	37	37	35.2	198.2	101.8	490	502.0	5354.1	67.4
	38	38	37	35.1	223.2	117.3	470	483.9	5946.9	67.2

TABLE 1 (continued)

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 9A @90V = 810 WATTS)

RELIANCE (9 AMP FIELD) STRAIGHT DC TESTS, 25-45°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
64	33	32	33	67.2	16.8	0.1	1215	1156.3	12.1	0.6
	34	34	36	66.6	36.9	11.4	1175	1129.3	1384.8	43.7
	35	35	38	65.6	64.2	26.1	1135	1107.2	3027.6	61.6
	36	35	40	64.6	94.1	42.2	1095	1084.9	4796.6	70.2
	34	34	40	64.0	121.7	60.1	1055	1054.4	6639.2	77.2
	34	34	40	63.5	156.0	78.8	1015	1023.0	8445.7	78.2
	35	34	42	62.8	196.5	102.1	975	994.0	10632.8	79.4
	35	35	42	62.3	237.1	122.3	935	961.6	12321.3	77.1
80	35	35	35	83.6	19.3	0.1	1530	1464.2	15.3	0.6
	36	36	37	82.8	45.0	12.7	1490	1440.1	1916.2	43.4
	35	35	36	82.3	65.1	24.2	1450	1409.0	3572.4	59.4
	36	36	36	81.4	87.6	36.4	1410	1385.3	5283.0	67.6
	37	36	40	80.7	110.2	49.5	1370	1358.1	7043.2	73.2
	38	38	42	80.0	139.4	67.6	1330	1329.7	9417.5	78.7
	41	40	44	79.6	176.1	84.7	1290	1296.9	11508.6	81.2
	41	41	47	78.8	198.5	100.7	1250	1269.5	13393.6	80.2
	41	41	49	78.3	227.9	118.7	1210	1237.5	15389.7	80.8
	41	41	50	77.7	154.9	135.0	1170	1207.1	17073.1	80.5
96	35	35	39	101.8	21.0	0.1	1880	1773.1	18.6	0.7
	35	35	41	101.5	47.0	13.2	1840	1740.1	2406.5	45.2
	35	36	41	99.8	60.7	20.5	1800	1730.8	3717.4	56.0
	36	36	44	98.8	76.1	31.0	1760	1709.8	5553.2	68.4
	38	37	45	98.0	98.8	41.0	1720	1685.2	7238.9	70.3
	38	38	45	97.5	117.8	52.5	1680	1653.9	9097.1	75.1
	39	38	46	97.1	141.4	67.8	1640	1621.3	11517.7	80.1
	39	40	48	96.5	165.5	81.3	1600	1591.5	13556.0	80.1
	39	39	46	95.9	189.5	96.4	1560	1561.1	15776.7	83.0
	40	40	47	95.5	213.3	111.7	1520	1528.8	17891.1	84.0
	39	39	47	94.7	250.6	130.9	1480	1501.2	20587.9	82.8

TABLE 2

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 6A @60V = 360 WATTS)

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RELIANCE (6 AMP FIELD) STRAIGHT DC TESTS, 25-45°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
96	43	42	44	101.3	18.3	0.1	2150	2037.5	21.3	1.0
	43	43	45	100.7	30.7	6.8	2100	2002.2	1426.4	43.1
	43	43	46	100.0	49.5	15.3	2050	1967.0	3153.0	61.7
	44	43	47	99.5	65.5	22.3	2000	1929.2	4507.3	67.8
	44	44	47	98.7	82.8	32.1	1950	1895.6	6375.1	76.7
	44	44	50	98.3	104.4	44.6	1900	1855.1	8668.4	83.5
	44	44	47	97.5	125.9	53.8	1850	1820.9	10263.7	82.5
	44	44	52	96.6	149.7	67.0	1800	1787.9	12550.3	85.2
	44	44	51	96.4	171.8	79.3	1750	1742.5	14477.1	85.9
	45	44	51	95.5	200.6	92.0	1700	1709.5	16477.5	84.0
	45	44	52	94.5	222.5	103.8	1650	1677.8	18246.2	84.0
	45	44	53	94.2	156.9	122.4	1600	1632.6	20936.1	83.7

TABLE 3

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 3A @30V = 90 WATTS)

RELIANCE (3 AMP FIELD) STRAIGHT DC TESTS, 25-45°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
96	34	35	39	101.2	15.4	0.1	3100	2941.8	30.8	2.0
	35	35	39	100.3	33.2	6.1	2950	2822.9	1804.1	55.1
	36	36	39	99.7	50.6	12.5	2800	2696.6	3531.5	71.4
	37	37	39	98.8	72.6	20.5	2650	2574.0	5528.4	78.3
	36	36	41	98.1	95.4	29.9	2500	2444.8	7831.5	84.7
	36	36	41	97.1	123.3	41.0	2350	2322.0	9974.3	83.6
	37	36	41	96.4	158.1	56.2	2200	2191.8	12905.4	84.5
	37	36	43	95.3	199.0	73.4	2050	2064.8	15878.5	82.7
	36	36	43	93.8	244.4	94.0	1900	1946.5	19169.8	81.4
	35	36	43	92.4	301.2	119.8	1750	1822.6	22876.1	78.9

TABLE 4

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 2.3A @23V = 53 WATTS)

RELIANCE (2.3 AMP FIELD) STRAIGHT DC TESTS, 25-45^{o}C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (^{o}C) #1	MOTOR FIELD TEMP (^{o}C) #2	MOTOR ARMATURE TEMP (^{o}C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
96	39	39	39	100.7	15.3	0.1	3800	3621.6	37.9	2.4
	41	40	41	100.2	27.6	3.3	3600	3448.4	1192.2	44.1
	42	40	42	99.6	41.7	7.5	3400	3276.8	2574.8	63.5
	42	42	43	98.9	55.4	12.3	3200	3104.8	4001.0	74.5
	42	42	43	98.3	75.6	20.1	3000	2828.9	5957.3	81.5
	42	42	43	97.5	98.4	27.2	2800	2755.3	7851.9	82.7
	42	42	45	96.6	123.3	37.0	2600	2582.6	10011.4	84.2
	43	43	44	96.0	154.2	51.2	2400	2399.6	12871.9	86.6
	43	43	44	95.1	196.5	66.9	2200	2221.5	15570.7	82.3
	43	43	45	93.3	250.8	90.2	2000	2060.4	19471.2	80.7
	43	43	48	92.0	317.8	116.5	1800	1882.8	22980.8	75.2

TABLE 5

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 9A @144V = 1296 WATTS)

RELIANCE (9 AMP FIELD) STRAIGHT DC TESTS, 130-150°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
16	133	132	134	16.8	9.9	0.0	285	271.3	0.0	0.0
	133	134	134	16.6	21.5	6.3	265	255.0	168.3	10.2
	134	134	134	16.4	39.2	16.4	145	238.3	409.5	21.3
	135	135	135	16.2	66.4	30.3	225	222.0	704.7	29.9
	135	135	135	16.1	95.8	45.2	205	203.6	964.2	34.0
	135	135	136	16.0	122.1	65.1	185	184.8	1260.4	38.8
	137	137	136	15.8	150.9	78.5	165	167.3	1375.9	37.1
	138	137	139	15.6	176.1	93.5	145	149.1	1460.6	35.5
	138	138	137	15.5	203.3	105.9	125	130.1	1443.5	31.7
24	134	135	123	25.1	11.8	0.1	435	415.8	4.4	0.2
	135	134	123	24.9	24.0	7.1	415	400.3	297.8	15.9
	135	135	123	24.7	44.4	17.0	395	383.5	683.0	28.9
	135	135	123	24.6	63.1	29.9	375	366.2	1147.2	28.9
	135	135	125	24.6	93.7	42.8	355	349.1	1565.4	44.2
	137	136	125	24.1	115.9	56.2	335	333.2	1961.9	48.1
	138	138	126	23.9	140.6	71.9	315	316.9	2387.2	51.1
	138	138	126	23.6	165.6	88.6	295	300.1	2785.7	52.9
	138	138	124	23.6	192.8	104.8	275	280.8	3083.1	52.1
36	132	132	112	37.7	14.5	0.1	670	639.9	6.7	0.3
	133	133	112	37.6	22.5	5.2	650	621.5	338.6	16.1
	133	133	112	37.3	37.6	12.9	630	607.4	820.9	31.0
	133	133	112	37.1	54.3	22.5	610	592.0	1395.5	42.9
	132	132	112	36.6	74.5	34.3	590	580.0	2084.3	52.4
	133	133	113	36.5	96.6	43.3	570	561.3	2546.3	53.7
	133	133	112	36.4	115.4	55.3	550	543.1	3146.6	57.7
	132	132	111	36.0	142.4	71.9	530	530.8	3998.5	62.3
	132	132	112	35.7	166.6	95.0	510	514.4	4580.9	62.8
	132	132	112	35.5	195.1	100.8	490	497.6	5255.0	63.2
	132	132	114	35.4	220.4	113.3	470	479.3	5689.5	61.6

TABLE 5 (continued)

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 9A @144V = 1296 WATTS)

RELIANCE (9 AMP FIELD) STRAIGHT DC TESTS, 130-150°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
64	131	131	125	66.4	15.8	0.1	1215	1170.3	12.3	0.5
	131	131	128	65.7	36.2	11.8	1175	1144.6	1415.0	39.2
	132	131	128	65.4	64.9	23.2	1135	1111.2	2700.9	49.6
	131	132	126	64.7	91.5	40.7	1095	1083.5	4620.2	64.6
	132	132	128	64.1	123.8	59.8	1055	1053.0	6597.3	71.6
	134	134	129	63.6	158.7	79.3	1015	1021.1	8483.5	74.1
	135	135	133	63.2	196.2	97.2	975	987.4	10055.3	72.6
	136	135	133	62.5	220.4	112.6	935	959.3	11316.9	73.5
80	136	136	131	83.5	20.2	0.1	1530	1465.0	15.3	0.5
	137	136	132	82.7	43.1	13.2	1490	1440.7	1992.4	42.0
	137	137	133	82.0	63.4	22.5	1450	1413.9	3333.0	52.3
	138	137	134	81.4	85.9	36.6	1410	1385.9	5314.3	65.1
	137	137	132	80.7	108.7	49.9	1370	1358.1	7100.1	71.1
	137	137	133	80.1	134.8	65.5	1330	1329.1	9120.8	75.5
	138	137	133	79.5	166.0	84.0	1290	1298.4	11426.7	78.4
	138	138	134	78.8	198.3	100.2	1250	1270.4	13336.5	77.7
	139	138	133	78.1	224.3	117.8	1210	1241.1	15317.4	79.6
	138	138	134	77.7	253.4	134.6	1170	1207.1	17022.5	78.9
96	131	131	105	101.3	21.9	0.1	1880	1781.9	18.7	0.5
	131	131	108	100.7	30.8	7.8	1840	1753.1	1432.6	33.7
	132	131	108	99.9	50.0	16.8	1800	1728.9	3043.1	50.0
	132	132	107	99.6	62.9	25.7	1760	1695.5	4565.3	62.2
	134	134	108	98.5	80.9	38.1	1720	1675.8	6689.3	73.8
	134	134	109	97.7	101.5	49.0	1680	1649.7	8469.1	76.7
	134	134	109	97.5	124.0	62.5	1640	1614.8	10573.9	80.1
	134	134	111	96.6	150.2	75.0	1600	1589.8	12492.2	79.5
	135	134	111	95.7	175.9	89.6	1560	1565.6	14696.8	80.8
	135	135	111	95.3	200.2	103.2	1520	1531.3	16556.7	80.7
	135	134	111	94.5	229.0	119.5	1480	1503.9	18828.7	80.8

TABLE 6

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 6A @96V = 576 WATTS)

RELIANCE (6 AMP FIELD) STRAIGHT DC TESTS, 130-150°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
96	134	134	106	100.6	18.6	0.1	2150	2051.7	21.5	0.9
	136	136	108	100.1	30.9	7.0	2100	2012.9	1476.2	41.7
	135	134	109	99.3	48.4	15.1	2050	1982.3	3136.0	60.0
	135	135	108	98.6	60.5	22.2	2000	1946.7	4527.8	70.9
	134	134	108	98.2	80.5	32.1	1950	1906.1	6410.4	77.2
	134	134	106	97.6	100.6	40.9	1900	1868.3	8005.8	78.2
	134	134	106	96.6	119.6	51.3	1850	1838.0	9878.6	81.9
	133	133	105	96.5	142.7	63.3	1800	1790.8	11876.4	83.2
	132	132	104	95.6	167.6	75.6	1750	1758.5	13928.3	83.6
	132	132	104	94.6	193.4	89.6	1700	1726.0	16202.5	84.6
	132	132	105	94.4	217.4	101.3	1650	1679.6	17825.8	83.1
	132	132	105	93.5	242.0	114.7	1600	1644.0	19756.0	83.0

TABLE 7

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 3A @48V = 144 WATTS)

RELIANCE (3 AMP FIELD) STRAIGHT DC TESTS, 130-150^{o}C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (^{o}C) #1	MOTOR FIELD TEMP (^{o}C) #2	MOTOR ARMATURE TEMP (^{o}C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
96	131	130	132	101.3	15.6	0.1	3100	2937.9	30.8	1.8
	132	131	132	101.1	31.4	6.4	2950	2800.9	1978.0	62.6
	132	132	131	100.2	50.5	12.1	2800	2681.7	3399.6	68.1
	132	132	132	99.7	73.1	20.4	2650	2549.6	5449.2	76.1
	133	133	132	98.7	96.3	28.9	2500	2431.0	7360.7	78.3
	133	132	134	98.1	124.0	40.9	2350	2299.1	9851.8	81.8
	133	132	134	97.5	157.6	56.2	2200	2166.0	12753.5	83.5
	133	133	134	96.4	198.6	73.6	2050	2042.3	15748.2	82.0
	132	132	133	95.2	142.0	94.2	1900	1916.6	18915.4	80.9
	133	132	134	93.0	303.2	120.5	1750	1818.2	22853.3	78.1

TABLE 8

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 2.3A @37V = 85 WATTS)

DEN3-123

RELIANCE (2.3 AMP FIELD) STRAIGHT DC TESTS, 130-150°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
96	132	132	142	101.1	16.3	0.1	3800	3607.2	37.8	2.3
	134	134	145	100.8	28.0	4.0	3600	3427.8	1436.5	51.8
	133	133	146	100.4	41.1	8.0	3400	3249.5	2723.6	67.6
	133	133	146	99.8	56.2	13.4	3200	3076.0	4318.4	78.8
	134	134	145	99.5	75.2	20.1	3000	2894.7	5095.8	83.4
	134	134	145	98.6	98.7	28.2	2800	2726.4	8055.1	84.3
	134	134	145	97.8	123.5	36.9	2600	2552.5	9867.9	82.6
	134	134	146	96.8	155.0	50.7	2400	2379.2	12637.9	84.4
	135	135	148	96.0	197.0	67.0	2200	2199.6	15440.2	81.3
	135	135	149	94.6	244.4	87.5	2000	2030.1	18610.6	79.0
	135	135	150	83.0	315.0	114.5	1800	1852.1	22337.9	73.7

TABLE 9

RELIANCE MODEL EV250AT DC SHUNT MOTOR DEN3-123
GENERAL ELECTRIC EV-1 CONTROLLER
(FIELD LOSS = 9A @90V = 810 WATTS)

RELIANCE (9 AMP FIELD) CHOPPED DC TESTS, 25-45°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
16	38	38	41	100.2	102.1	4.6	26.8	411.8	15.9	21.4	13.3	43.9	362.7	285	1.0	29.9	2.5
	38	37	41	100.2	101.0	12.1	42.8	1028.6	16.0	24.1	36.7	73.8	854.2	265	15.0	416.5	25.0
	38	37	42	99.9	101.0	18.8	55.7	1693.1	15.9	29.2	63.5	97.2	1420.9	245	27.6	708.5	31.8
	37	36	41	98.7	100.5	24.4	65.1	2122.1	15.8	31.5	87.4	116.9	1719.1	225	44.0	1037.2	41.0
	36	36	40	98.4	99.7	31.3	76.6	3859.5	15.8	33.7	115.9	142.7	2271.9	205	59.7	1282.2	41.6
	37	36	40	97.5	99.7	40.1	92.8	3575.9	15.9	35.6	150.7	168.5	3097.4	185	78.7	1525.4	39.0
	36	36	40	96.7	99.5	48.4	106.0	4137.5	15.8	35.6	185.0	202.7	3549.2	165	97.8	1590.7	38.8
	36	36	40	96.6	100.4	59.1	122.6	4860.6	16.1	36.4	218.7	233.8	4217.7	145	115.6	1656.1	34.9
	37	36	40	94.5	98.0	66.6	133.5	5399.9	15.8	34.6	240.3	253.1	4593.2	125	131.4	1720.8	31.8
24	36	36	36	101.2	102.5	4.7	23.5	380.3	23.7	26.7	11.4	36.5	297.7	435	0.2	9.1	0.8
	36	36	36	100.5	102.5	7.8	34.1	730.4	23.6	28.0	22.5	54.9	628.3	415	6.3	273.9	19.0
	36	36	36	99.8	101.5	15.6	46.8	1427.4	23.8	34.5	44.6	78.1	1281.3	395	17.7	732.5	35.0
	36	36	36	98.6	101.6	25.1	65.5	2300.6	23.8	36.4	70.5	102.5	2056.2	375	30.6	1202.2	41.9
	36	36	36	97.7	99.8	36.5	77.8	3301.3	23.8	38.6	102.5	131.1	2983.2	355	50.1	1863.4	49.1
	35	35	35	96.6	99.3	45.5	94.5	4318.9	23.9	43.5	129.0	153.6	3790.7	335	62.4	2190.1	47.6
	35	35	35	95.0	97.7	57.7	108.1	5038.3	23.8	44.0	164.7	184.7	4531.6	315	82.2	2712.8	50.8
	35	35	35	93.6	98.2	69.8	127.1	6084.4	23.9	44.4	197.1	213.0	5332.8	295	100.7	3112.3	50.7
	36	35	35	92.4	97.1	83.4	147.6	6864.7	23.6	41.4	226.8	237.2	5988.1	275	119.5	3443.0	50.6
36	32	32	33	101.3	102.4	4.6	23.6	574.8	36.0	38.7	11.0	30.6	470.7	670	2.0	140.4	11.0
	32	32	32	99.7	100.6	15.2	44.5	1608.2	36.0	43.6	30.8	62.2	1421.1	650	10.6	721.7	32.3
	31	31	32	97.6	99.5	30.5	65.9	2813.2	36.1	46.5	60.3	90.8	2542.4	630	25.4	1676.5	50.0
	31	30	31	97.4	99.4	39.5	76.3	3628.6	36.0	47.8	77.5	105.7	3248.6	610	35.6	2275.2	56.0
	31	31	32	96.0	97.6	53.6	92.4	4698.9	36.0	50.3	106.0	128.8	4389.7	590	41.0	3152.5	60.6
	31	31	30	94.2	97.5	65.9	110.3	5870.4	36.0	51.3	126.4	149.4	5343.9	570	62.4	3725.4	60.7
	29	29	30	93.5	96.6	82.0	129.8	7270.6	36.0	53.2	157.6	175.5	6629.7	550	79.9	4604.1	61.9
	29	29	31	91.4	95.5	95.4	144.4	8080.9	36.0	51.4	187.8	201.0	7494.2	530	94.3	5236.3	63.1
	33	33	36	90.4	93.9	112.3	166.5	9197.4	36.0	52.0	214.6	227.5	8384.9	510	112.1	5989.8	65.1
	33	33	37	88.6	93.6	134.1	192.4	10594.3	36.0	50.2	250.2	259.9	9597.5	490	131.5	6750.8	64.9
	36	36	39	87.1	93.0	154.3	210.6	11922.9	35.0	50.4	267.8	282.7	10544.7	470	144.7	7125.3	62.8

TABLE 9 (continued)

RELIANCE MODEL EV250AT DC SHUNT MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

DEN3-123

RELIANCE (9 AMP FIELD) CHOPPED DC TESTS, 25-45°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE	TEMPERATURE °C			CHOPPER INPUT VOLTAGE		CHOPPER INPUT CURRENT (AMPS)		CHOPPER INPUT POWER	CHOPPER OUTPUT VOLTAGE		CHOPPER OUTPUT CURRENT (AMPS)		CHOPPER OUTPUT POWER	MOTOR OUTPUT			
NOMINAL	FIELD #1	FIELD #2	ARMATURE	AVG.	RMS	AVG.	RMS	(WATTS)	AVG.	RMS	AVG.	RMS	(WATTS)	SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
64	31	31	31	101.3	102.7	4.5	17.0	475.9	63.5	65.6	6.1	18.3	410.6	1215	0.5	63.6	5.2
	32	32	32	97.6	99.6	28.6	50.7	2875.1	63.8	69.1	45.8	58.3	2541.2	1175	12.0	1477.2	44.1
	34	33	35	96.4	97.6	44.9	68.0	4295.8	64.0	71.5	56.6	77.9	4099.3	1135	23.2	2758.8	56.2
	33	34	34	92.6	94.2	77.7	101.8	6990.8	63.9	70.9	97.6	116.7	6688.5	1095	45.5	5220.0	69.6
	31	31	30	89.8	93.0	112.5	140.5	10042.9	63.8	73.2	140.9	157.9	9527.7	1055	70.5	7792.5	75.4
	32	32	31	86.5	89.2	156.3	182.0	13760.8	63.7	71.0	188.4	200.7	12579.1	1015	96.6	10262.5	76.7
	32	32	31	81.6	84.5	209.9	231.0	16732.1	63.8	68.9	242.5	250.5	15836.9	975	127.2	12993.5	78.1
	35	35	34	76.1	77.9	269.6	281.8	20093.4	63.5	66.6	293.9	300.6	19094.5	935	155.6	15242.5	76.6
80	35	34	37	98.8	99.8	10.5	14.6	1098.2	80.0	83.1	10.5	18.1	956.3	1530	0.7	112.2	6.4
	34	34	36	95.5	97.4	40.9	51.7	3913.1	80.1	83.4	45.7	56.1	3725.1	1490	14.2	2216.7	48.9
	34	33	37	93.4	95.4	70.9	85.3	6805.4	79.9	83.0	78.4	91.0	6625.0	1450	32.4	4922.1	66.2
	34	34	37	91.4	92.1	100.9	112.8	9301.0	79.9	82.7	108.4	119.6	9037.4	1410	49.6	7327.2	74.4
	34	34	36	87.4	88.7	142.1	148.1	12572.2	80.1	81.3	146.9	154.6	12256.5	1370	73.4	10535.4	80.6
	35	35	38	85.2	86.4	158.1	163.0	13749.0	78.7	80.7	166.6	170.0	13348.3	1330	81.4	11342.5	80.1
	35	34	38	84.5	85.5	171.1	176.4	14690.5	77.5	78.1	180.3	185.9	14367.9	1290	91.5	12366.5	81.5
	35	35	38	83.5	84.6	191.0	196.1	16072.7	76.3	77.6	201.2	204.7	15632.1	1250	100.0	13096.2	79.7
	34	35	37	82.5	83.5	201.4	207.3	16878.1	74.2	76.5	211.7	217.2	16247.0	1210	108.8	13792.7	80.9
	38	37	41	80.5	81.4	212.0	218.6	17300.1	72.9	74.5	223.0	228.2	16792.2	1170	117.0	14341.9	81.5

TABLE 10

RELIANCE MODEL EV250AT DC SHUNT MOTOR FIELD LOSS = 9A @144V = 1296 WATTS DEN3-123

GENERAL ELECTRIC EV-1 CONTROLLER

RELIANCE (9 AMP FIELD) CHOPPED DC TESTS, 130-150°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
16	137	137	139	101.3	102.5	6.7	28.8	616.4	15.9	21.5	23.8	55.8	480.5	285	3.9	116.5	6.6
	136	136	138	100.3	102.7	16.8	50.3	1478.0	16.2	26.5	53.8	89.3	1259.3	265	22.9	635.8	24.9
	136	135	137	99.4	101.4	23.1	60.5	1958.3	16.1	30.3	78.5	111.2	1682.9	245	38.6	990.8	33.3
	135	135	137	98.5	100.5	29.9	70.2	2584.1	15.9	32.9	107.4	134.1	2156.5	225	55.0	1296.5	37.6
	135	135	137	98.5	100.5	35.8	85.4	3320.4	16.1	35.6	132.7	155.8	2940.1	205	66.5	1428.3	33.7
	135	135	136	97.3	100.3	40.4	92.0	3538.0	15.9	36.3	154.5	174.0	3120.2	185	79.4	1538.9	34.8
	135	135	137	96.5	99.8	47.3	104.7	4097.3	16.0	34.9	178.2	197.2	3560.8	165	93.6	1618.1	33.3
	135	135	137	95.1	99.6	57.5	122.3	4721.8	16.0	34.5	210.9	225.3	4116.0	145	111.9	1699.9	31.4
	135	135	138	94.4	98.5	65.6	132.0	5199.9	15.9	34.5	227.7	208.1	4469.9	125	121.8	1595.1	27.7
24	140	140	147	99.6	100.7	14.9	45.4	1381.0	24.1	32.2	37.7	72.2	1271.1	435	14.0	638.0	24.9
	141	140	147	98.5	100.6	25.3	63.5	2478.1	24.3	37.3	64.4	99.7	2272.8	415	28.9	1256.6	35.2
	140	140	148	96.4	98.5	37.4	77.3	3137.4	24.1	37.6	94.9	123.6	2753.9	395	45.1	1866.4	46.1
	139	140	145	96.3	98.5	42.0	84.8	3644.3	24.1	41.2	108.5	134.6	3216.2	375	54.5	2141.2	47.5
	139	139	146	94.6	97.5	52.5	101.3	4575.0	24.1	42.4	138.8	159.8	4134.3	355	68.0	2529.1	46.5
	139	139	146	93.9	98.5	61.4	114.4	5486.0	24.2	44.7	159.5	180.5	4994.3	335	81.7	2867.5	45.6
	139	139	145	93.5	97.4	69.8	125.6	5953.7	24.1	43.0	180.9	198.3	5305.9	315	93.6	3089.0	46.8
	139	139	144	92.5	96.5	79.1	137.9	6413.3	24.1	41.6	204.5	218.9	5705.0	295	106.7	3297.8	47.1
	139	139	145	90.8	96.4	89.6	151.9	7270.4	24.5	42.5	223.5	235.6	6487.0	275	119.0	3428.6	44.0
36	136	136	139	100.6	102.7	14.7	42.5	1446.9	36.1	42.4	27.7	58.6	1327.8	670	8.1	568.6	21.7
	136	136	140	100.3	102.5	22.6	56.3	2331.7	36.1	45.2	44.4	78.2	2156.3	650	16.7	1137.3	32.9
	137	137	139	98.4	100.9	38.2	75.4	3527.9	36.0	49.5	75.0	104.6	3269.0	630	34.1	2250.8	49.3
	137	137	140	96.5	99.6	48.4	85.5	4300.7	36.1	49.5	94.6	120.2	3876.9	610	44.6	2850.4	55.1
	138	137	141	95.6	98.4	57.1	97.3	5153.6	35.9	51.3	113.5	135.3	4734.6	590	56.2	3473.9	57.6
	137	137	141	94.6	97.9	70.5	113.9	6259.2	36.0	52.3	135.2	157.3	5775.1	570	68.4	4084.7	57.8
	138	137	137	93.5	97.4	81.3	127.4	7162.1	36.0	52.0	157.6	176.3	6561.5	550	79.5	4581.0	58.3
	138	138	142	91.7	96.4	103.2	154.9	8741.0	36.0	51.7	195.3	210.8	7082.2	530	99.1	5502.8	59.3
	139	139	140	91.0	95.4	111.4	160.5	9231.9	36.0	51.6	205.7	219.9	8385.8	510	105.3	5626.4	58.1
	139	138	140	88.6	94.4	131.1	184.1	10546.0	36.0	50.7	237.4	250.1	9593.1	490	123.5	6340.1	58.2
	140	140	141	88.6	93.6	145.5	199.8	11456.7	36.2	50.8	256.9	266.6	10300.1	470	132.3	6514.7	56.2

TABLE 10 (continued)

RELIANCE MODEL EV250AT DC SHUNT MOTOR FIELD LOSS = 9A @144V = 1296 WATTS · DEN3-123

GENERAL ELECTRIC EV-1 CONTROLLER

RELIANCE (9 AMP FIELD) CHOPPED DC TESTS, 130-150°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
64	136	136	138	98.4	99.6	21.0	42.4	2229.4	64.1	68.8	26.1	48.6	1942.0	1215	5.2	661.9	20.4
	136	136	137	97.3	99.7	40.3	69.8	4359.7	64.1	71.5	48.7	77.2	3990.1	1175	17.6	2166.6	41.0
	135	135	137	93.6	95.4	70.9	94.8	6507.3	64.0	71.9	89.6	109.3	6275.8	1135	40.5	4816.0	63.6
	136	136	137	91.4	93.6	94.2	120.7	8358.1	63.9	72.3	117.3	134.4	8057.1	1095	55.3	6344.2	67.8
	136	136	138	87.4	90.6	130.4	157.1	11610.0	64.0	72.6	157.7	172.9	11064.2	1055	78.8	8710.0	70.5
	136	136	138	85.3	88.5	159.1	183.9	13499.5	64.0	70.6	189.2	201.2	12952.5	1015	96.0	10208.7	71.6
	136	136	137	82.5	86.3	196.2	220.4	16225.5	63.3	70.2	229.9	238.9	15551.9	975	119.9	12247.8	72.7
	137	136	138	79.4	81.5	230.3	249.6	17964.6	63.0	67.2	258.1	265.2	16907.9	935	137.1	13430.2	73.8
80	142	143	149	98.6	100.4	30.1	43.7	3117.1	79.7	82.4	30.6	44.9	2600.5	1530	4.8	769.4	19.7
	143	143	150	96.4	97.6	52.2	65.7	5090.9	79.8	82.4	56.0	70.2	4786.8	1490	19.5	3044.1	50.0
	143	143	149	94.4	96.3	74.6	87.0	7012.9	79.8	82.5	79.2	90.3	6536.2	1450	32.1	4876.5	62.3
	143	143	149	91.5	92.5	102.8	115.0	9481.4	79.7	82.2	109.4	119.3	8875.5	1410	49.0	7238.5	71.2
	144	144	149	90.2	90.6	132.7	142.5	11916.1	79.3	80.9	139.1	146.3	11372.1	1370	65.8	9444.5	74.6
	143	143	149	86.4	88.4	162.1	165.5	14385.4	78.9	80.3	168.2	172.5	13666.8	1330	82.6	11509.8	76.9
	144	144	149	84.5	86.3	176.0	182.0	15127.1	77.5	78.6	182.8	186.5	14443.0	1290	89.1	12042.1	76.5
	144	144	150	84.4	84.9	188.9	196.3	16167.6	76.3	77.6	199.6	203.0	15531.9	1250	98.5	12899.7	76.7
	144	144	151	83.5	84.4	201.6	209.1	17109.0	74.2	75.4	211.5	216.8	16216.1	1210	107.2	13589.8	77.6
	144	144	152	82.5	83.5	215.4	221.0	17897.0	72.4	73.5	224.5	229.9	16679.1	1170	113.8	13949.6	77.6

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16. Abstract

Both straight and chopped DC motor performance data for a Reliance EV-250AT motor with a General Electric EV-1 controller are presented in tabular and graphical formats. Effects of motor temperature and operating voltage are also shown. The maximum motor efficiency is approximately 85% at low operating temperatures in the straight DC mode. Chopper efficiency can be assumed to be 95% under all operating conditions. For equal speeds, the motor operated in the chopped mode develops slightly more torque and draws more current than it does in the straight DC mode.

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